The 2023 International Workshop on the High Energy Circular Electron Positron Collider

October 23-27, 2023, Nanjing China

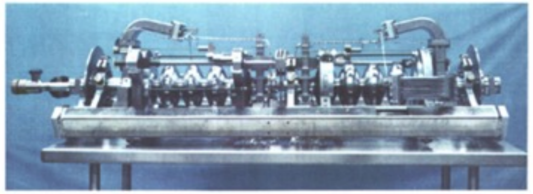
Historical view and perspective for SRF applications

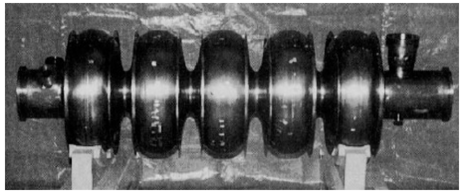
Carlo Pagani

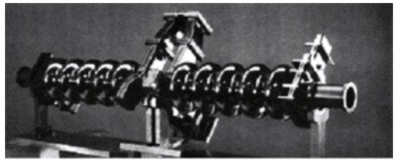
carlo.pagani@mi.infn.it

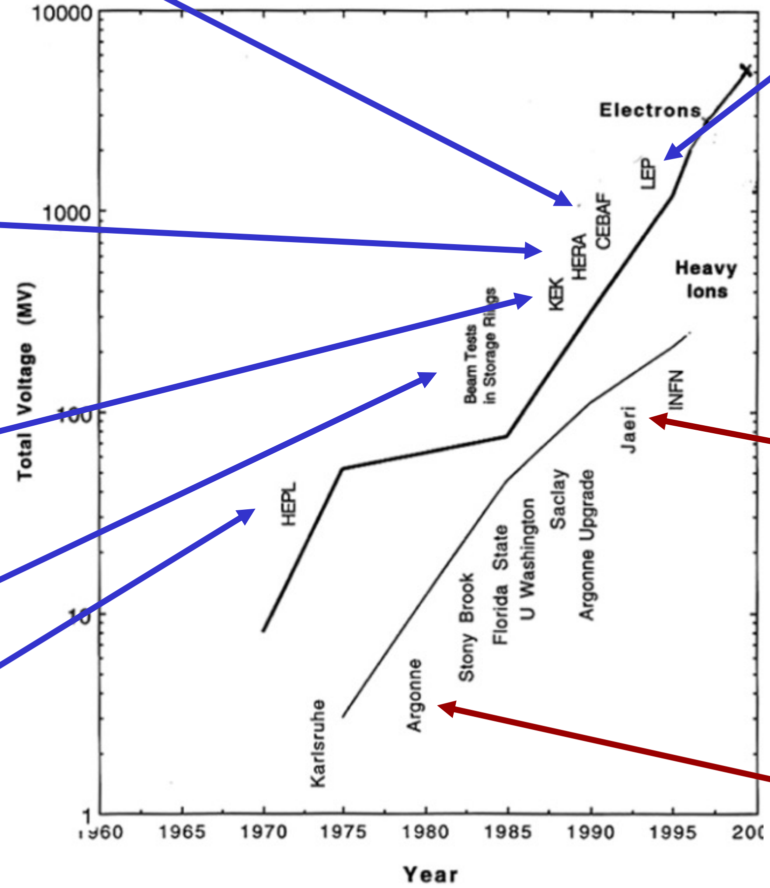
SCRF from HEPL to the TESLA effort

"Livingston Plot" from Hasan Padamsee



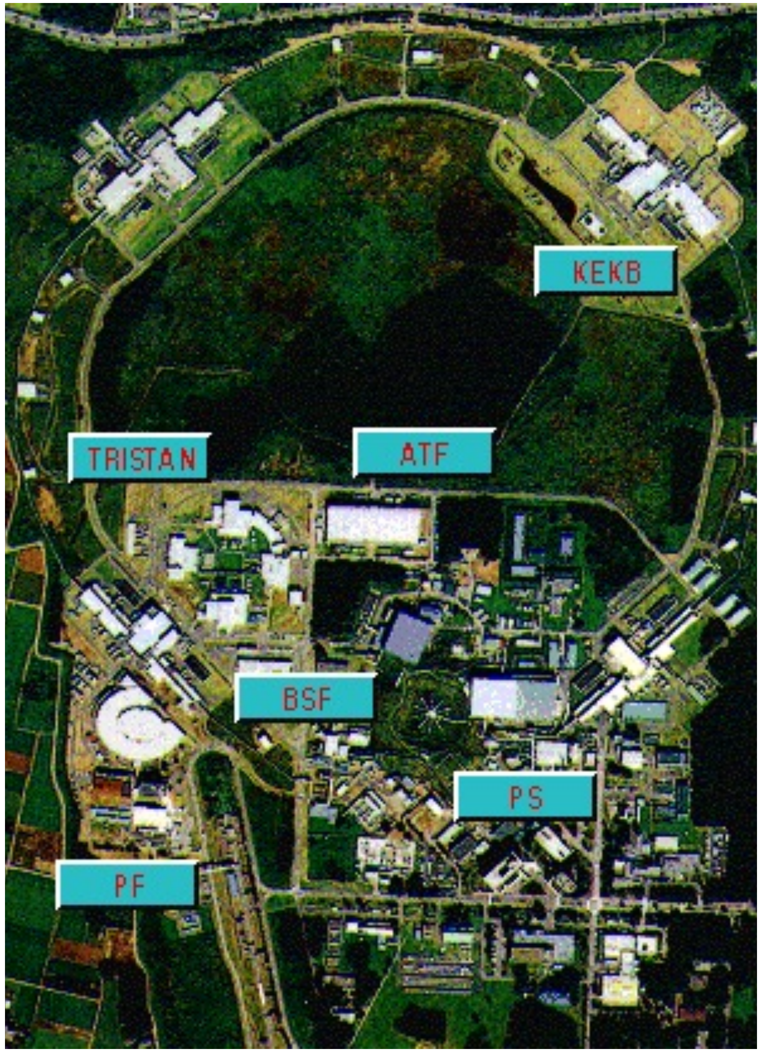




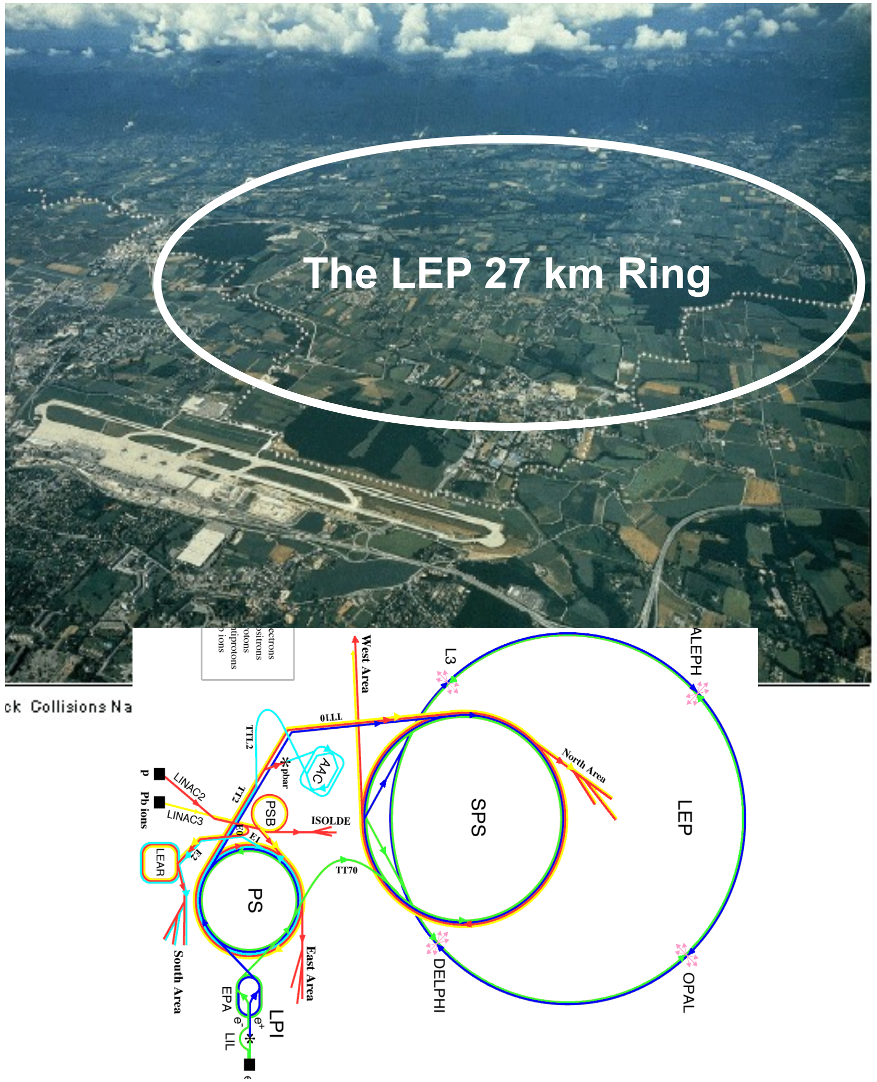


Largest Research Projects bet on SRF

TRISTAN at KEK

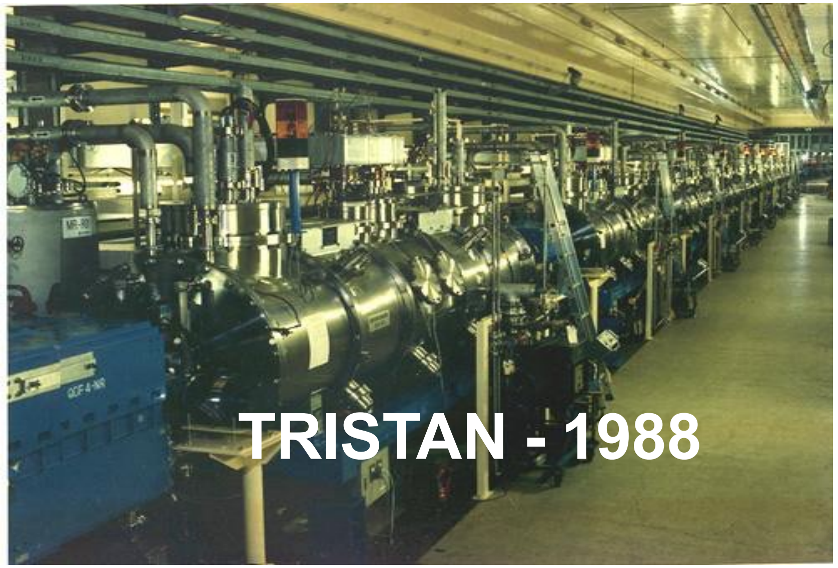


LEP2 at CERN



CEBAF at TJNAF

First Installed Cryomodules for $\beta = 1$



TRISTAN SRF from KEK to MHI

KEK 1981

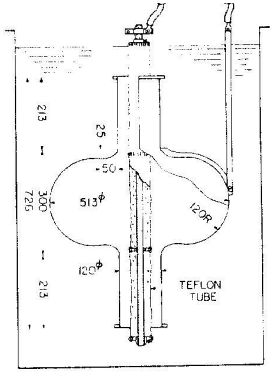


Fig. 1 Set up of the electropolishing.

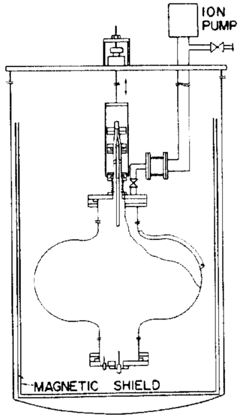


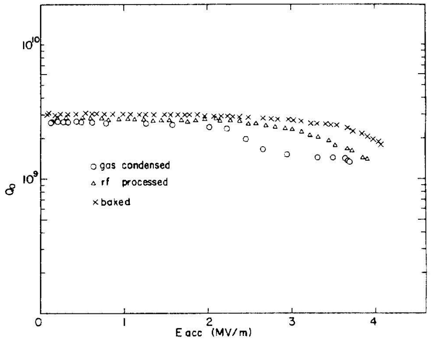
Fig. 2 Cavity assembly in the dewar.

Major impurities in the niobium used for the 500 MHz cavity.

Tantalum	1700 ppm
Tungsten	800 ppm
Zirconium	800 ppm
Silicon	500 ppm

T. Furuya, S. Hiramatsu, T. Nakazato, T. Kato
P. Kneisel*, Y. Kojima and T. Takagi

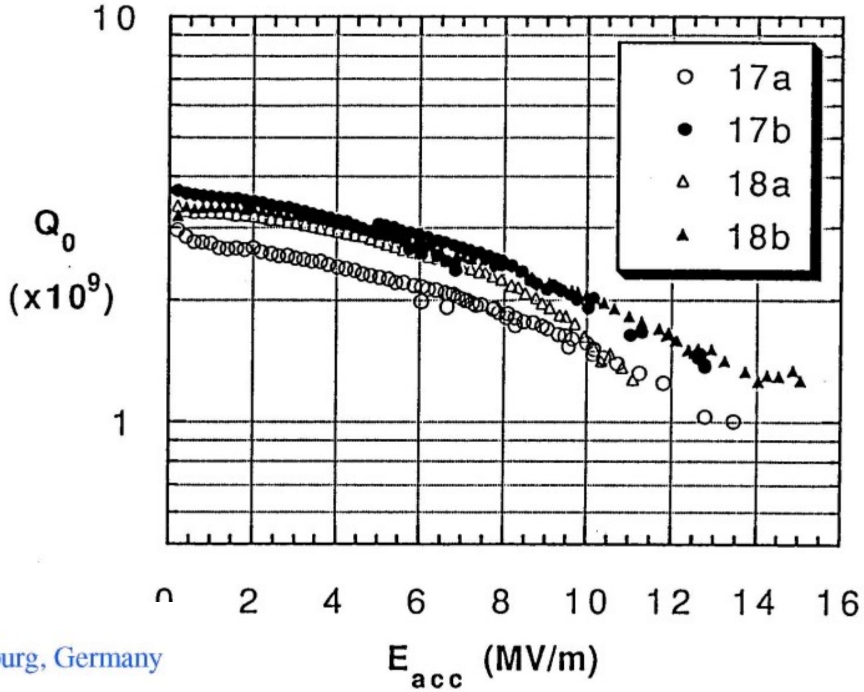
IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981



MHI 1995

Table 1. Results of final vertical measurements of spare cavities.

Cavity #	17a	17b	18a	18b
Meas. date	28 June 91	12 June 91	30 Jan. 91	7 Feb. 91
f_0 (MHz)	508.240	508.178	508.204	508.218
Q_{15D} 1) ($\times10^{11}$)	3.33	2.57	2.49	3.03
Q_0 at low field ($\times10^9$)	2.8	3.6	3.3	3.4
$E_{acc,max}$ (MV/m)	13.5	12.8	11.1	15.1



Proceedings of the Fifth Workshop on RF Superconductivity, DESY, Hamburg, Germany

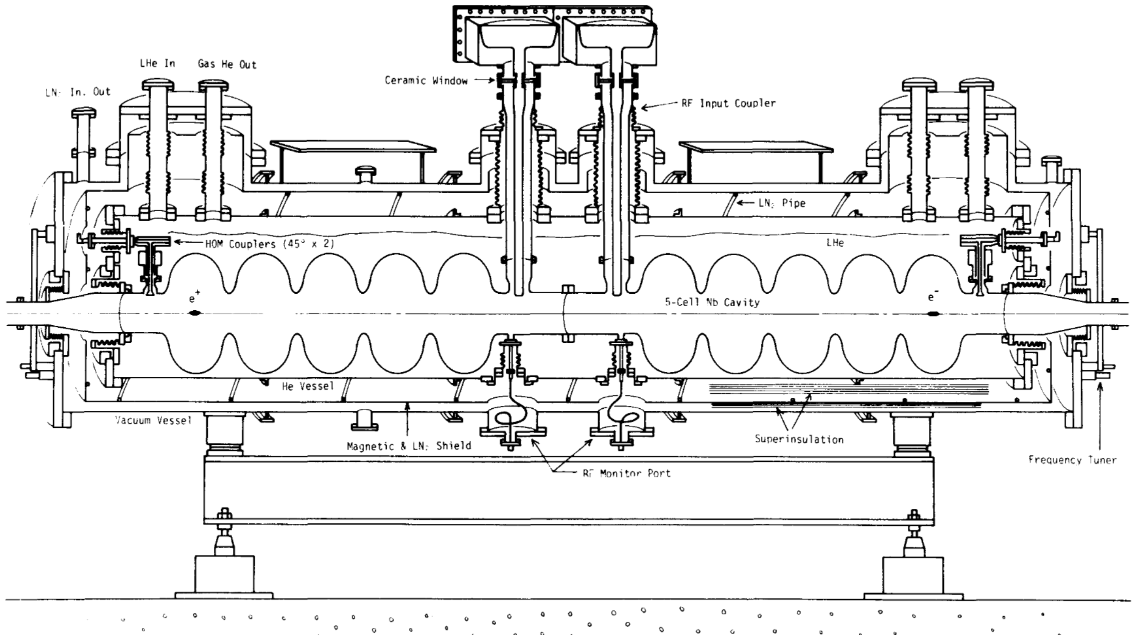
Successful Prototypes in 1987

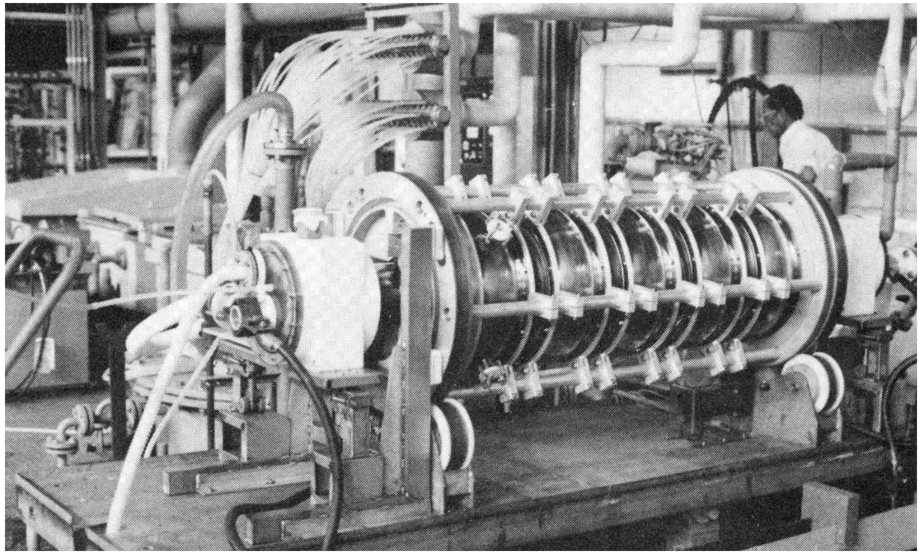
Proceedings of The Third Workshop on RF Superconductivity, Argonne National Laboratory, Illinois, USA

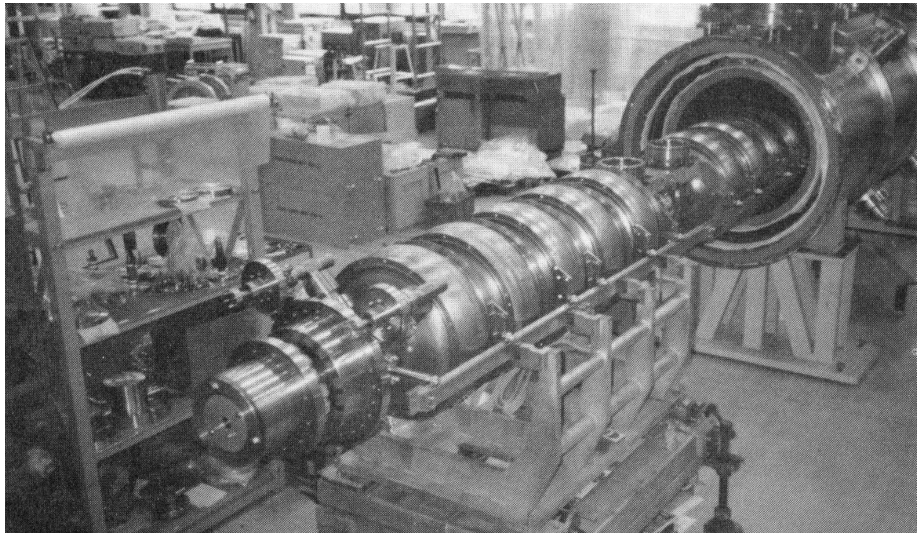
STATUS OF TRISTAN SUPERCONDUCTING RF PROGRAM

S. Noguchi, K. Akai, M. Arinaga, K. Asano, T. Furuya
K. Hara, K. Hosoyama, A. Kabe, Yuji Kojima, Yuzo Kojima
S. Mitsunobu, H. Nakai, T. Nakazato*, T. Ogitsu, K. Saito
U. Sakamoto T. Suzuki and T. Tajima

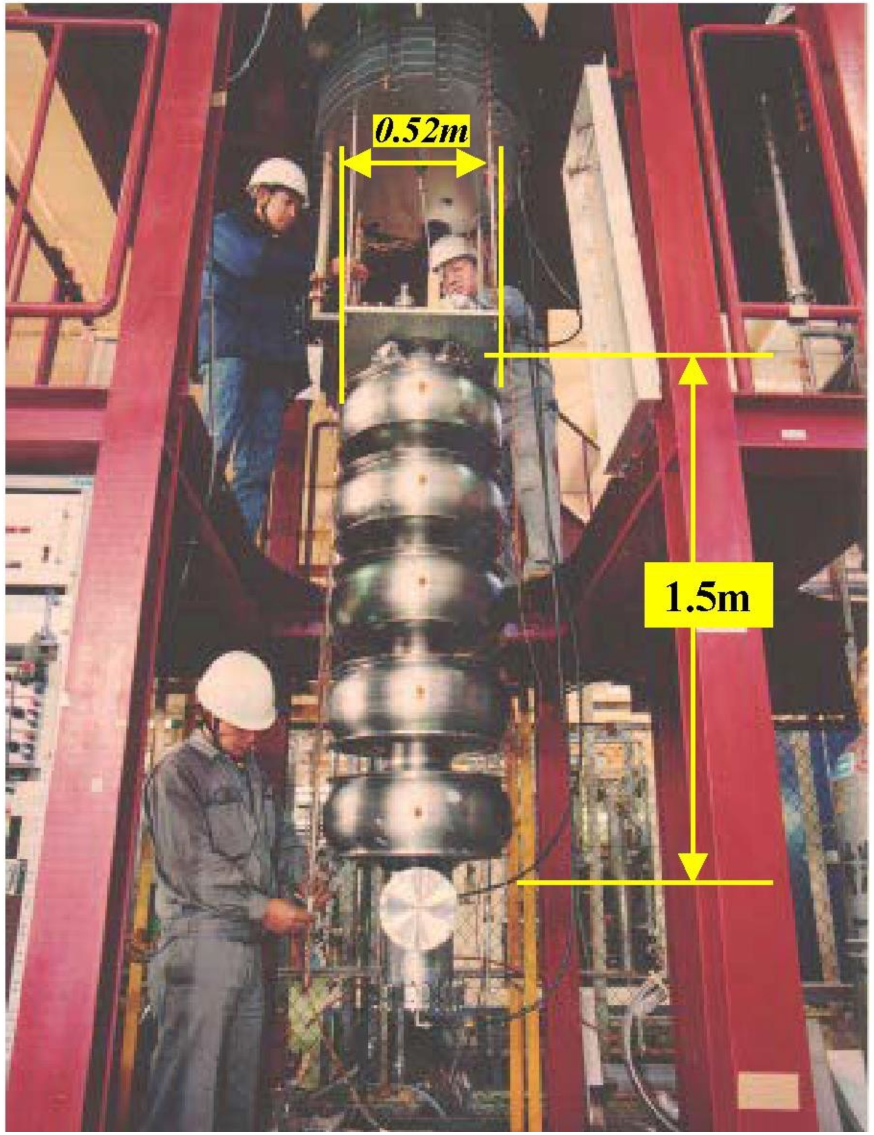
KEK, National Laboratory for High Energy Physics







First SFR Industrial Production: Japan 1988 –1995

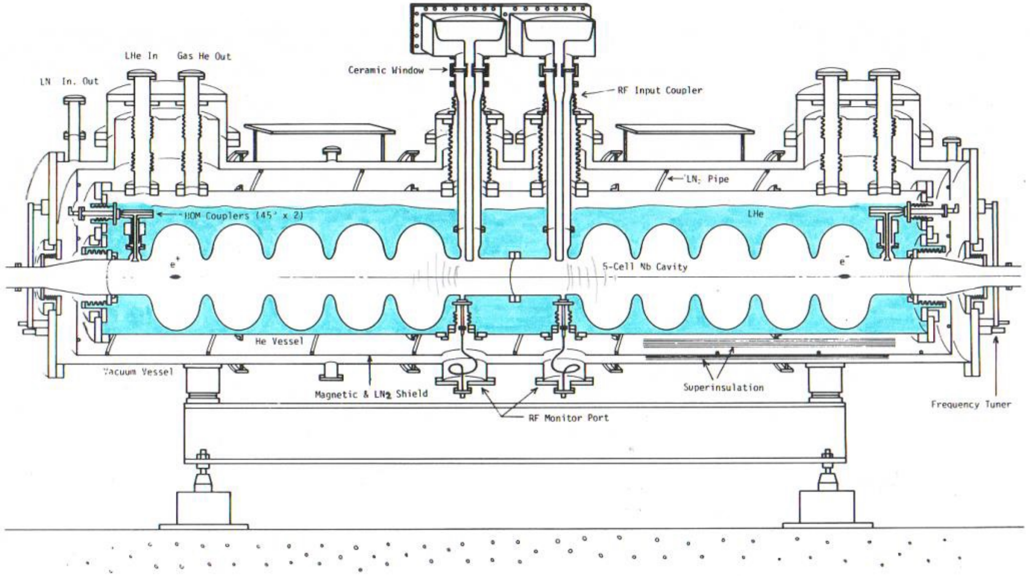


The **first mass-production** of SRF Cavities in the world

SRF Cavity **for TRISTAN** at **KEK**

Bulk-Nb - 508MHz - 5-Cell Cavity

32 SRF cavities were fabricated by Mitsubishi and operated in TRISTAN



SRF Operation Experience 1988-1995

Proceedings of the 1995 Workshop on RF Superconductivity, Gif-sur-Yvette, France

Experience on the Superconducting RF System in TRISTAN

Shuichi Noguchi
KEK; National Laboratory for High Energy Physics
1-1, Oho, Tsukuba, Ibaraki, 305, Japan

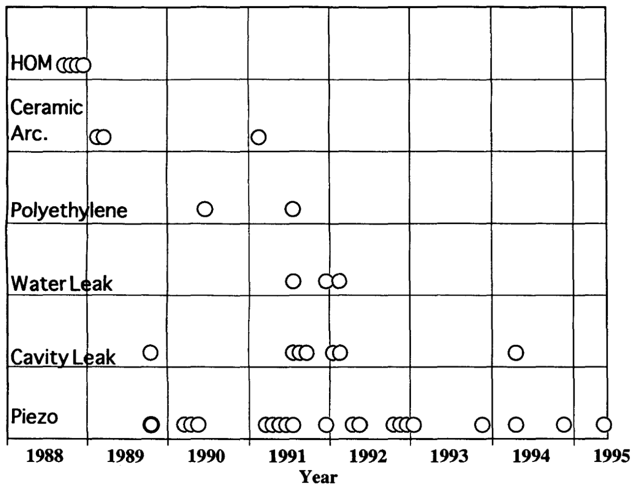


Table I, Summary of the operation of SRF Cavities in TRISTAN-MR.

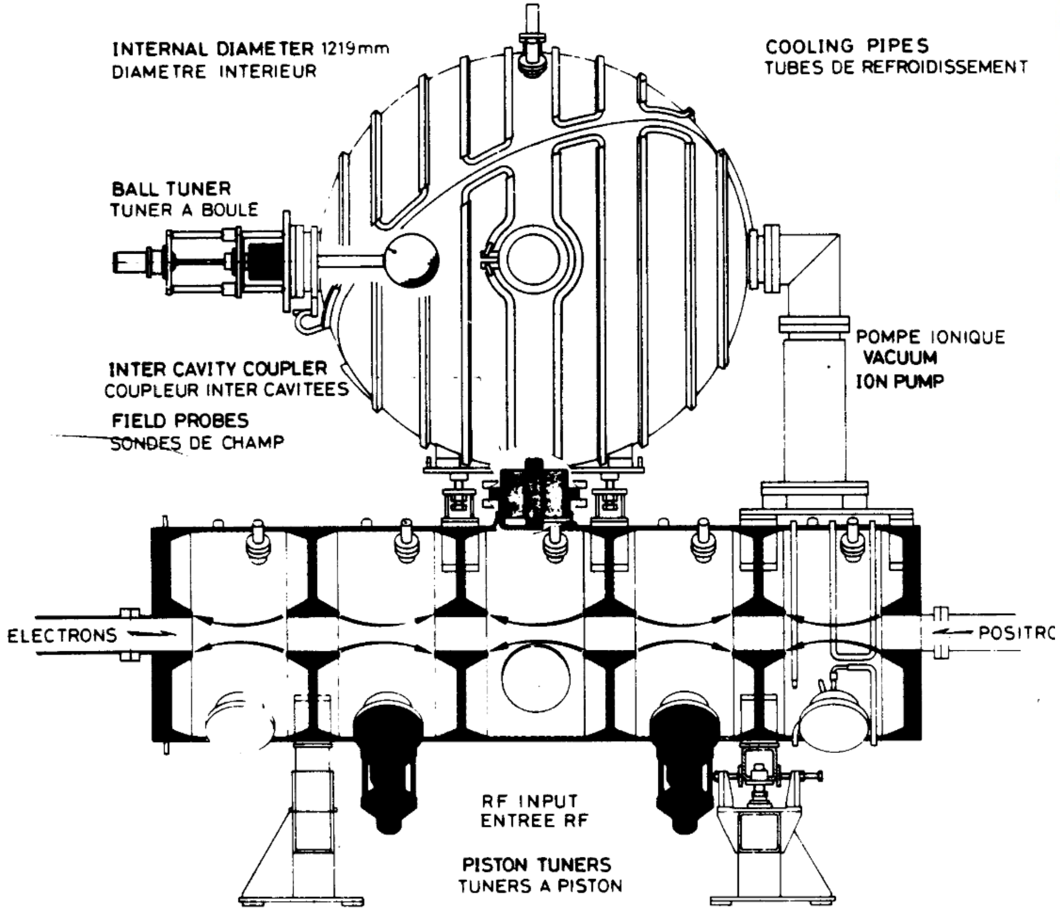
Period		Number of cav. (at 4K)	(operated)	Total Vc (MV)	Eacc(ave.) (MV/m)	Energy (GeV)	Current (mA)	Phys.Run (days)
1988	Nov-Dec	16	16	105-109	4.4-4.6	30.0	10	18
1989	Jan-Mar	16	14	82-88	4.0-4.2	30.4	9	49
	May-Jun	14	14	87	4.2	30.4	10	17
	Jun-Jul	16	16	105	4.4	30.7	10	37
	Nov-Dec	30	28-29	190-200	4.6-4.7	32.0	12	25
1990	Feb-Mar	32	31	160	3.5	29.0	12	37
	Apr-May	32	30-31	160	3.5-3.6	29.0	12	25
	May-Jun	32	28-30	150-160	3.6	29.0	13	39
	July	30	25	130	3.5	29.0	13	31
1991	Jan-Jul	32	29-30	140-145	3.3	29.0	9	36
	Oct-Dec	30	26	140	3.6	29.0	13	35
1992	Feb-Mar	26	23	125	3.6	29.0	12	31
	Apr-Jun	28	23-25	135-140	3.8	29.0	13	77
	Oct-Dec	32	25-31	150-170	3.3-4.1	28.8-29.9	13	66
1993	Feb-Apr	30-32	28-32	145	3.2	29.0	13	48
	May-Jun	32	28-32	145	3.2	29.0	13	48
	Oct-Dec	32	32	145	3.0	29.0	13	25
1994	Feb-Mar	32	32	155	3.2	29.0	15	38
	Apr-May	30	27	155	3.8	29.0	15	57
	June	30	30	160	3.6	29.0	15	26
	Oct-Dec	32	32	175	3.6	29.0	15	53
1995	Mar-May	32	32	175	3.6	29.0	15	53

Total accumulated time of cavities at 4.4 K : 33000 hours 13 cool down cycles

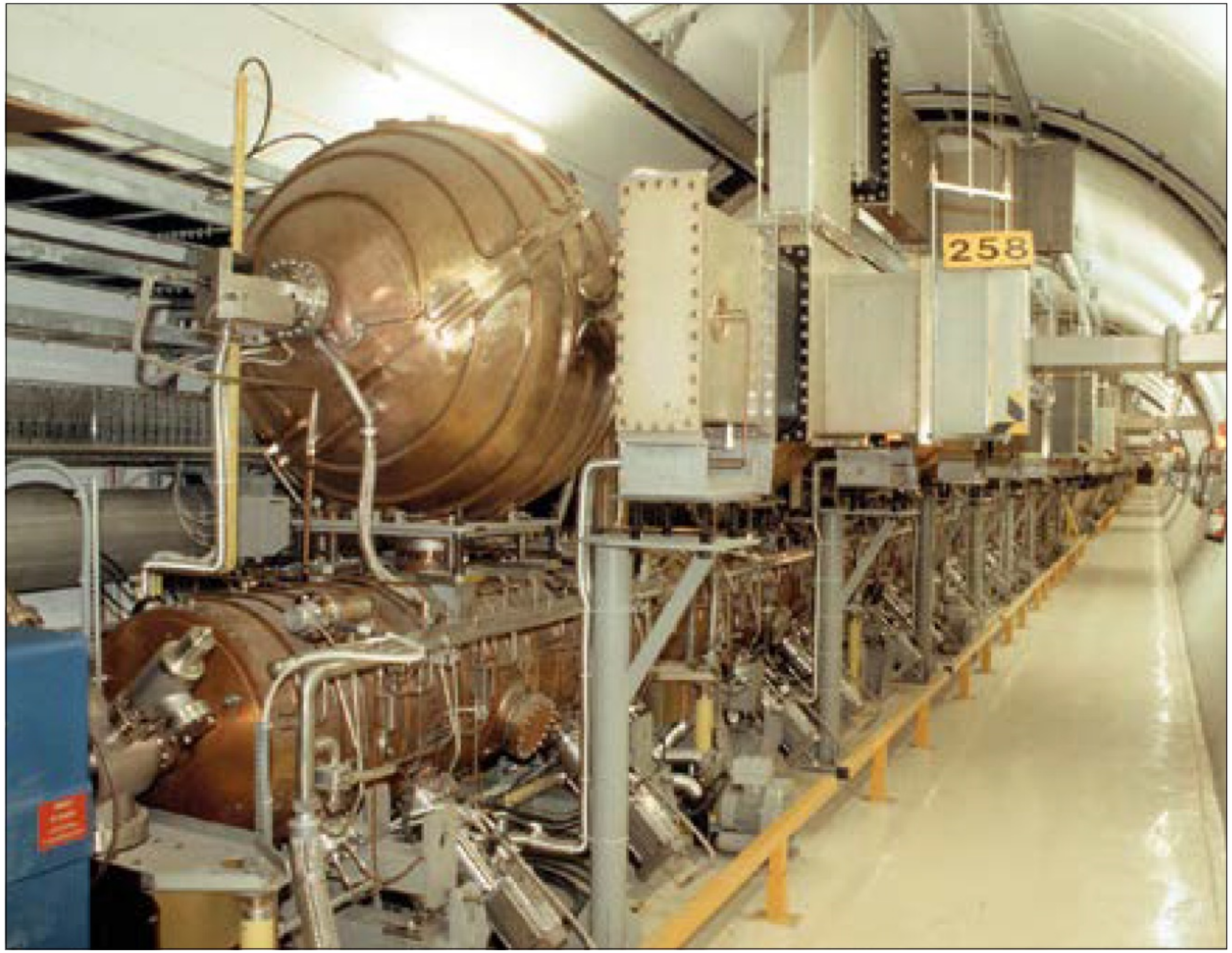
Conclusions

A system of thirty-two superconducting RF cavities was operated for seven years without serious problems. Operability and stability of the performance in an existing storage ring were demonstrated. There were several hardware troubles, but they were not essential and solved. Although it looks special in TRISTAN for the moment, a gas discharge triggered by synchrotron radiation and developed by adsorbed gases caused many RF trips. Fortunately with an enough ring voltage and an RF recovering procedure, this trip was acceptable in TRISTAN, but a reduction of synchrotron radiation as well as adsorbed gases is essential for a longer operation or a higher current application.

The LEP-1 RF System



All image credits: CERN



LEP2 at CERN: First SRF Cavity Prototype in 1985

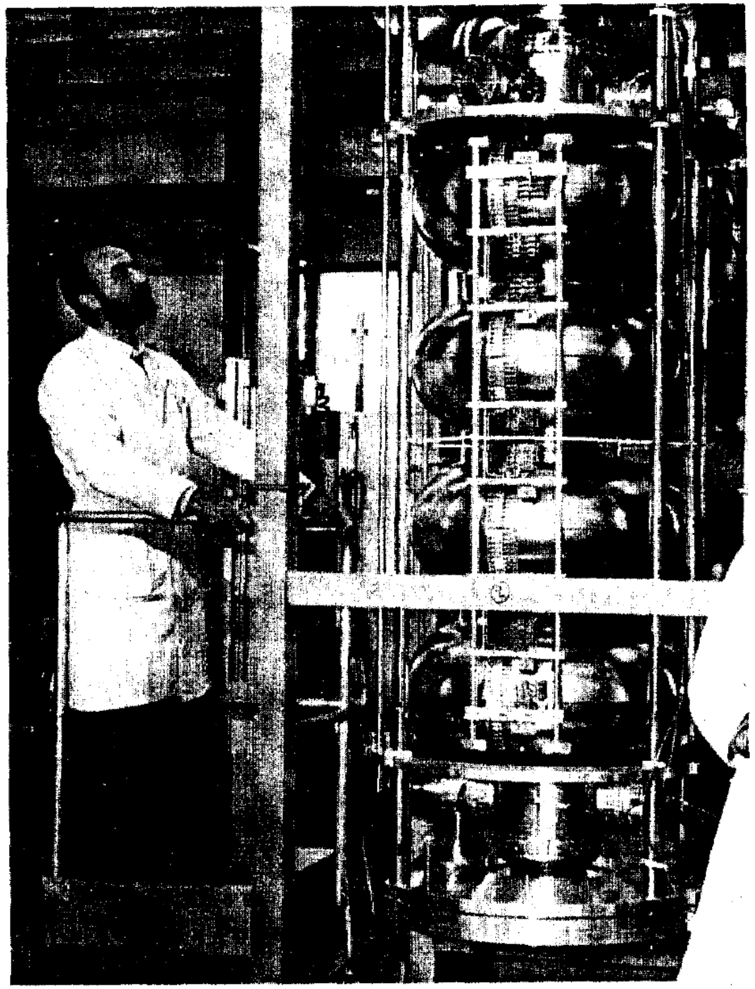


Fig. 2 The first superconducting 352 MHz prototype cavity for LEP in its vertical support. Visible in front is the arm carrying the resistor thermometers for temperature mapping.

A SUPERCONDUCTING 352 MHz PROTOTYPE CAVITY FOR LEP

G. Arnolds-Mayer(*), Ph. Bernard, D. Bloess, G. Cavallari, E. Chiaveri, E. Haebel, H. Lengeler, R. Stierlin, J. Tückmantel and W. Weingarten
CERN, Geneva, Switzerland
and H. Piel, Univ. of Wuppertal, W.-Germany

IEEE Transaction\ on Nuclear Scence. Vill. NS.32. Xi0 5, October 1985

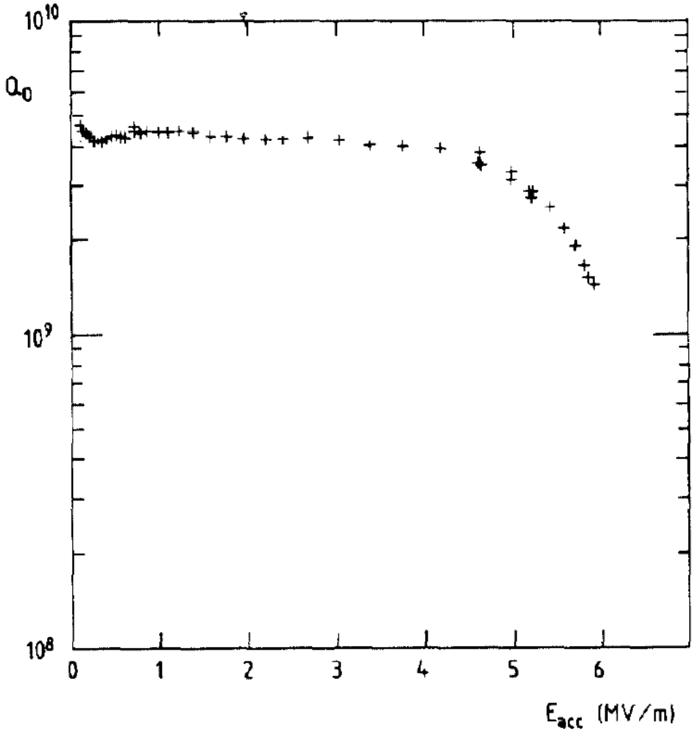


Fig. 5 Q value of the cavity as a function of the accelerating field (T = 4.2 K).

Frequency f	352.209 MHz
Cavity active length	1.70 m
Iris hole diameter	241 mm
Shunt impedance/quality factor r/Q	276 Ohm/m
E_p/E_{acc}	2.3(a)
H_p/E_{acc}	39 G/(MV/m)
Geometry factor G	280 Ohm
$2(f_\pi - f_o)/(f_\pi + f_o)$	1.76%
$-\Delta f/\Delta p$	~ 2 Hz/mbar(b)
$\Delta f/\Delta \ell$	45 Hz/µm

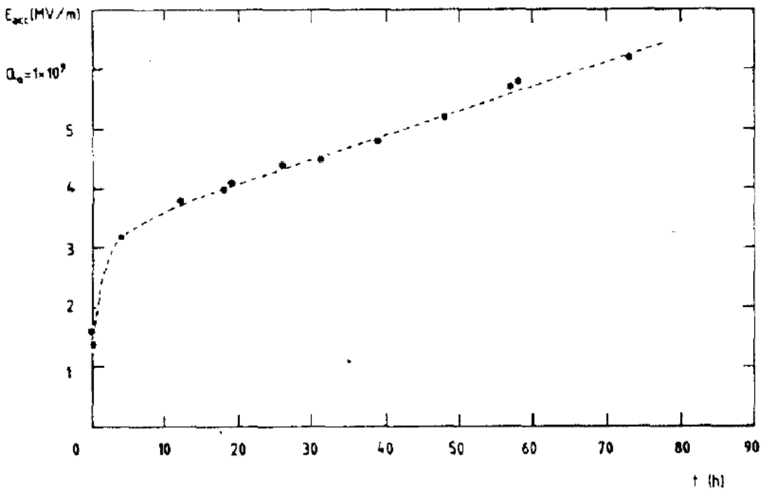


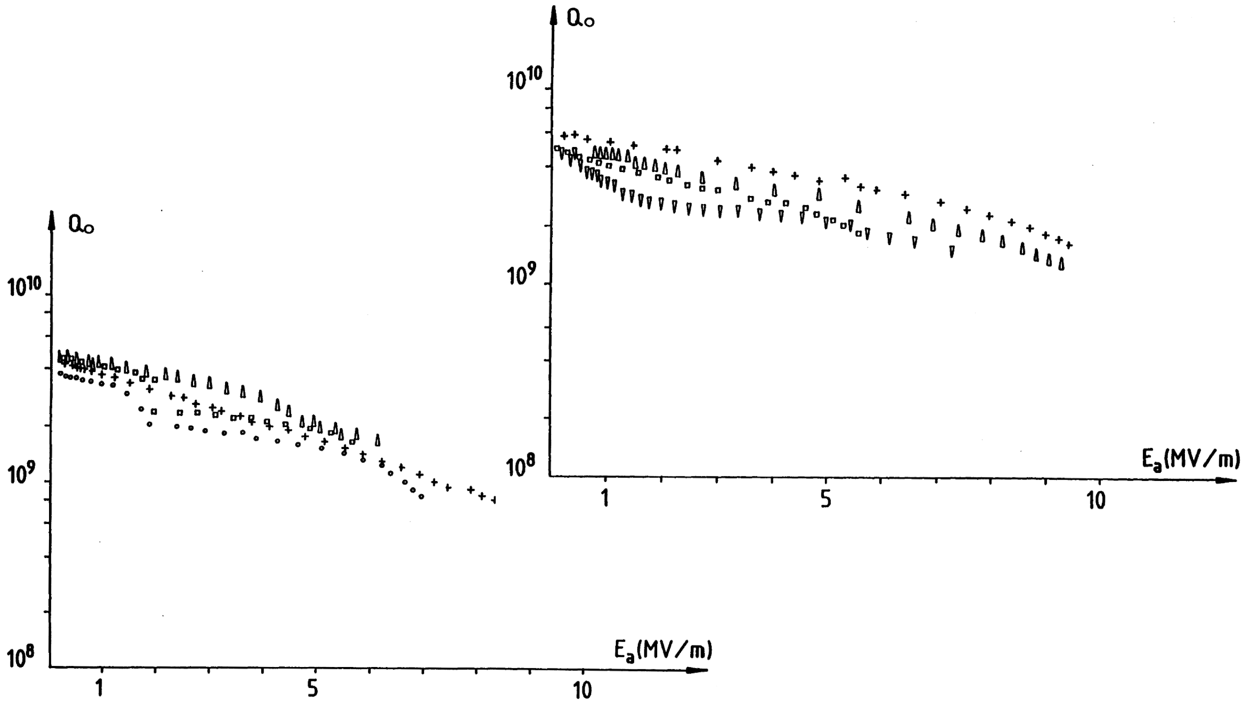
Fig. 4 Accelerating field at Q = 1 • 10⁹ as a function of the processing time (T = 4.2 K).

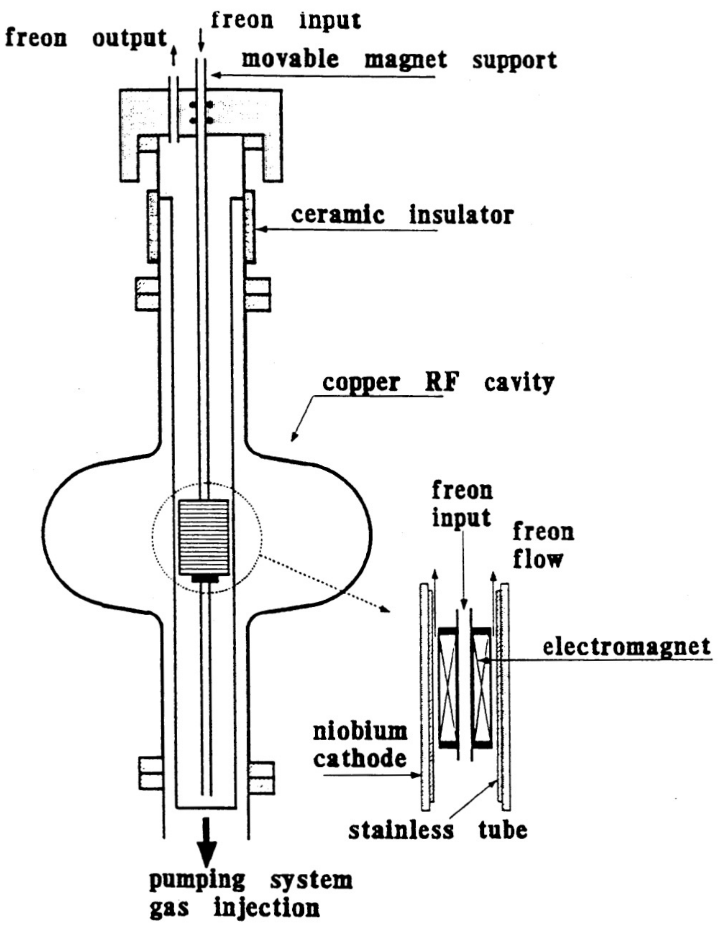
Outstanding Results with Nb on Copper in 1987

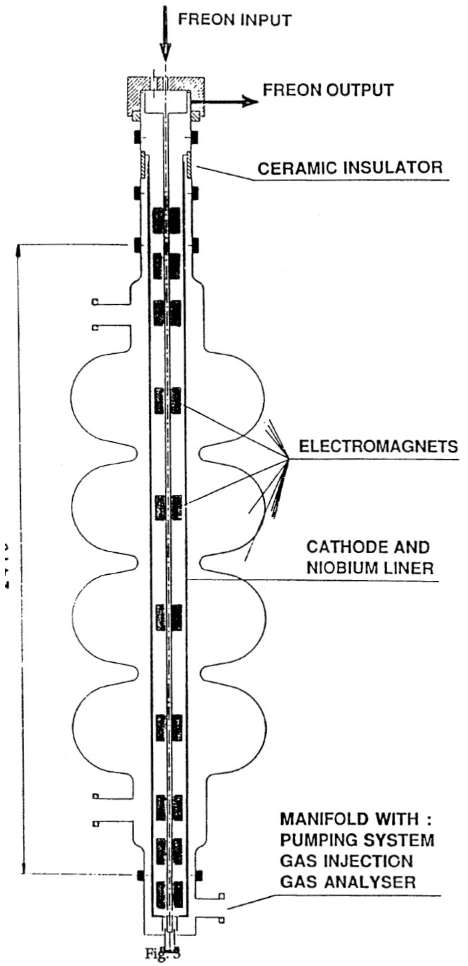
Third Workshop on RF Superconductivity, Argonne National Laboratory, Illinois, USA

SUPERCONDUCTING CAVITIES PRODUCED BY MAGNETRON SPUTTERING OF NIOBIUM ON COPPER

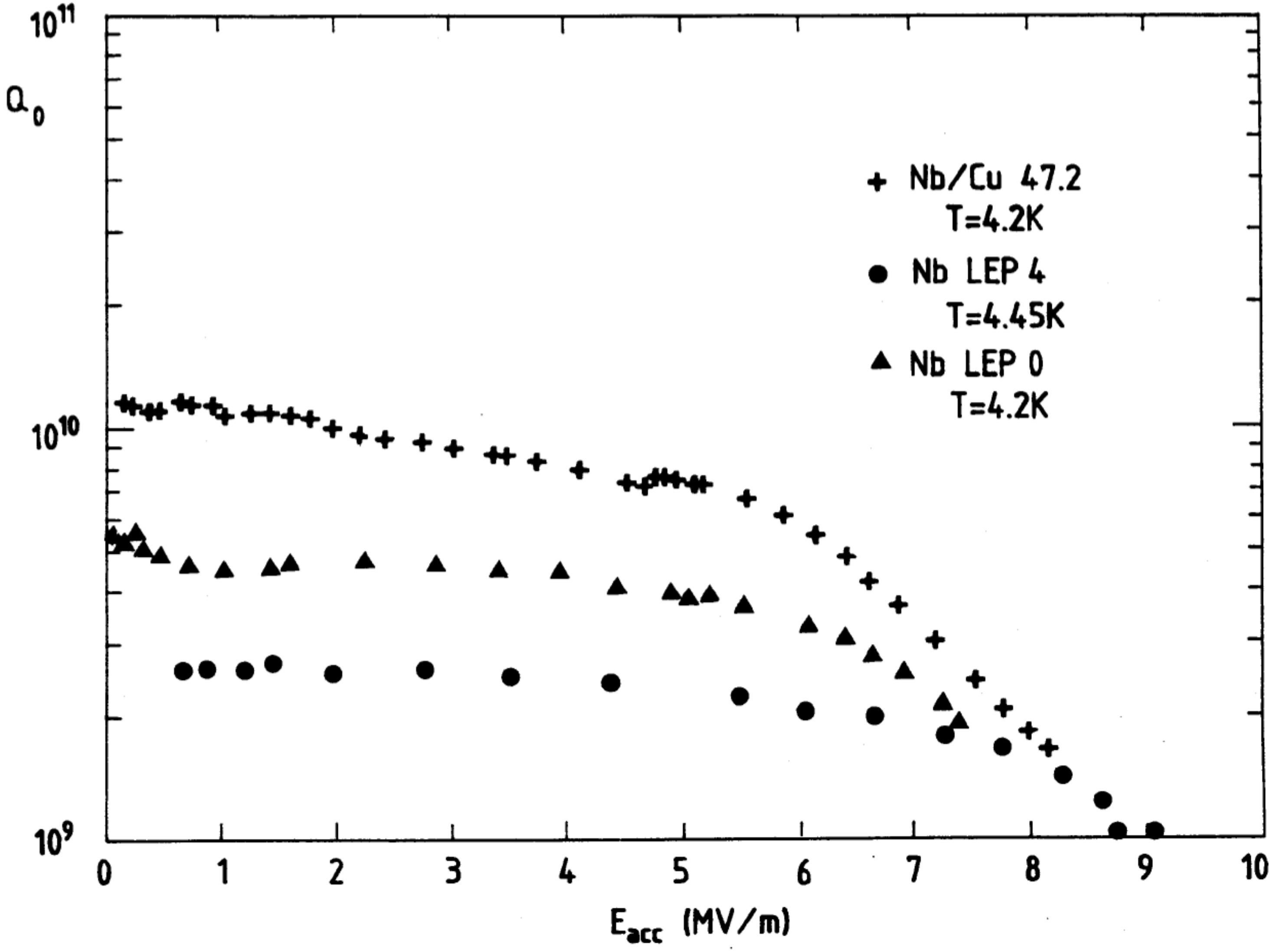
C. Benvenuti, D. Bloess, E. Chiaveri, N. Hilleret, M. Minestrini, W. Weingarten







Nb on Cu wins the competition for LEP2 in 1989



1989 Workshop on RF Superconductivity
Tsukuba, Japan, August 1989

Advantages:

- Less expensive
- Not dominated by the modest Niobium quality
- Unexpectedly less sensitive to the external magnetic field
- Higher Q_0 ⟶ higher field at the same cryo-losses

LEP2 Cavities move to Industry in 1990

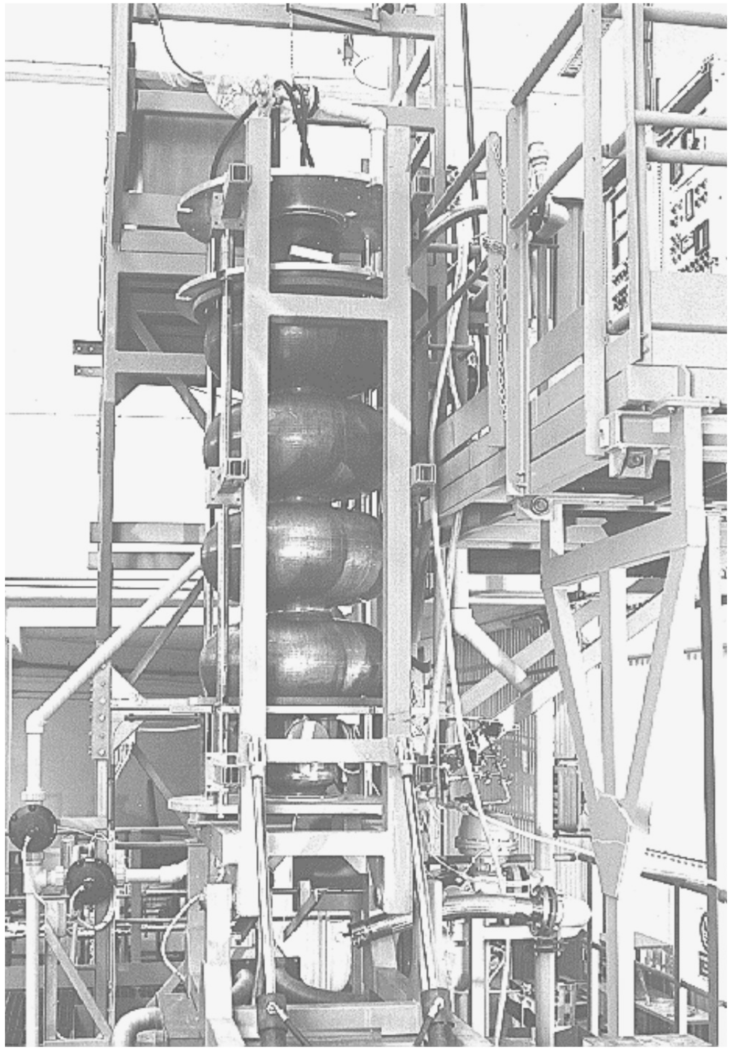
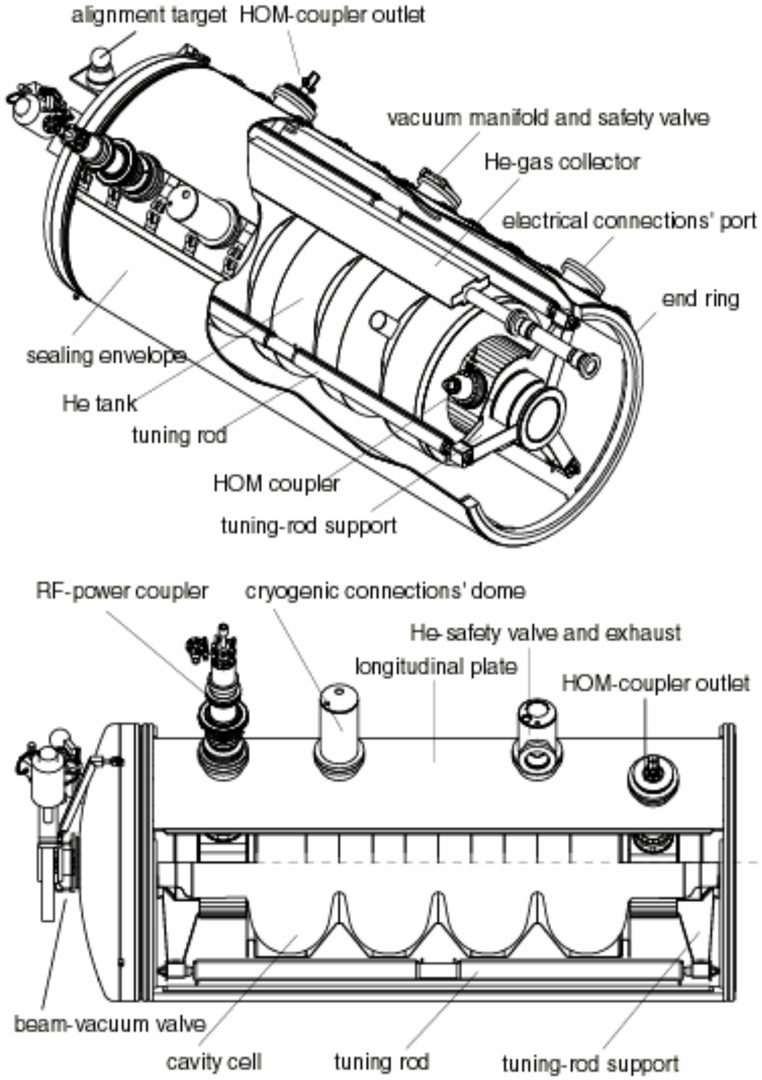


Fig. 2 - Chemical plant for cavity treatment



Gradient improvement with time

Proceedings of the 1999 Workshop on RF Superconductivity, La Fonda Hotel, Santa Fe, New Mexico, USA

Table 2: Present configuration of the LEP RF system

Cu cavities	48
Klystrons for Cu system	8
SC cavities	288
Klystrons for SC system	36
Maximum circumferential voltage	3560 MV

In order to reach the highest beam energy possible the voltage reserve is at the very minimum. This is demonstrated on the example of running at 100 GeV, calculated for a quantum lifetime of 24 h:

Synchrotron radiation loss:	2923 MV
Required for 24 h quantum lifetime:	3200 MV
With reserve for one HV trip	3390 MV
Typically available:	3420 MV

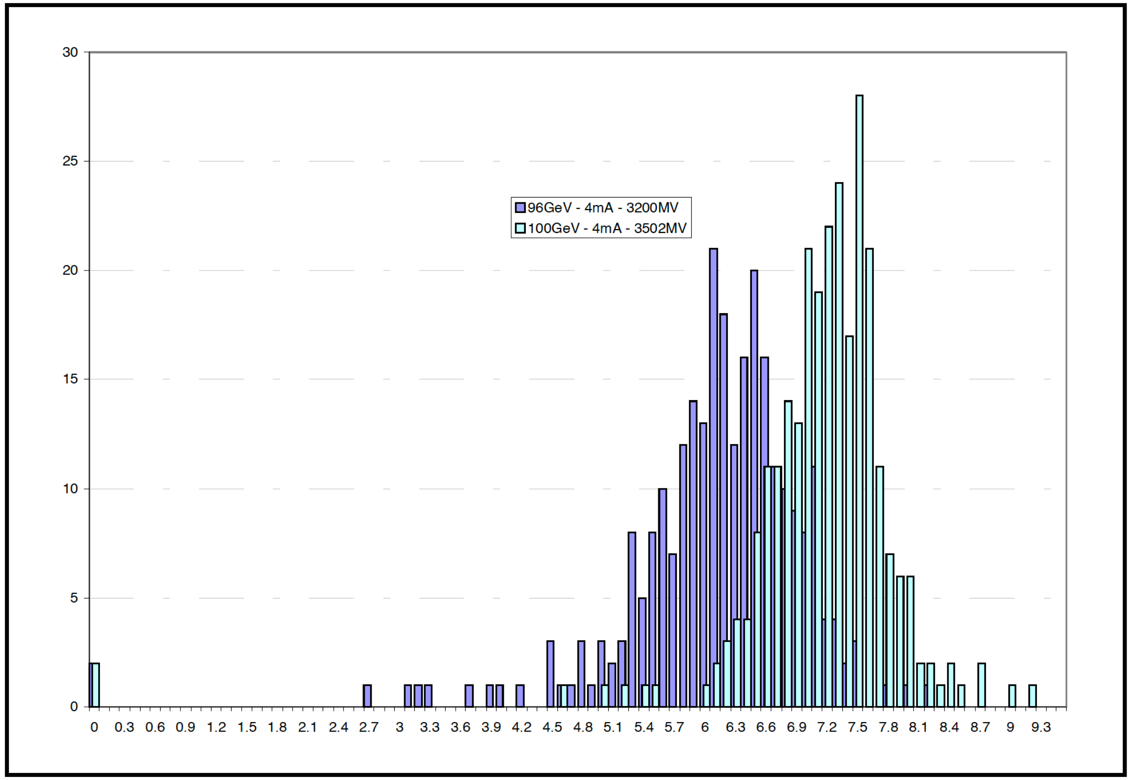


Fig. 7: Accelerating gradients at the beginning and at the end of 1999 operation

LEP 2 Energy Evolution

Proceedings of the 2001 Particle Accelerator Conference, Chicago

ULTIMATE PERFORMANCE OF THE LEP RF SYSTEM

P.Brown, O.Brunner, A.Butterworth, E.Ciapala, H.Frischholz, G.Geschonke, E.Peschardt, J.Sladen,
CERN, Geneva, Switzerland

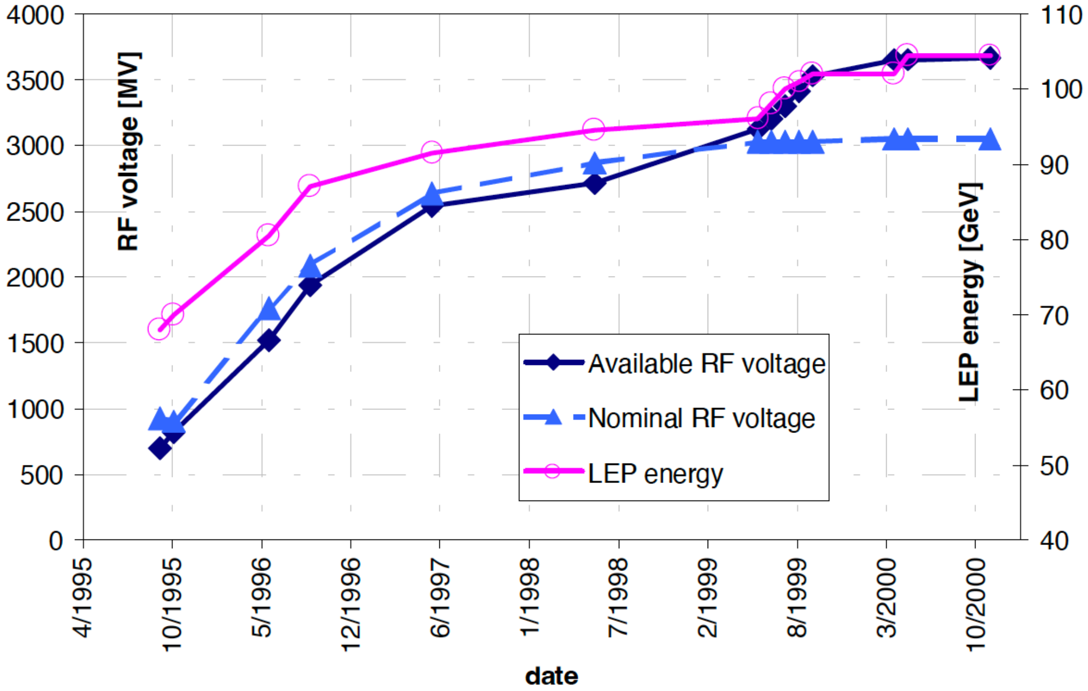


Figure 1.: Beam energy, available and nominal RF voltage from 1995 until 2000.

Table 1 The LEP RF system in 2000

number of Cu cavities	56
accelerating voltage per cavity	2.5 MV
active length of 4-cell cavity	1.7 m
number of solid Nb SC cavities	16
design gradient	5 MV/m
number of sputtered Nb SC cavities	272
design gradient	6 MV/m
number of klystrons (1/1.3 MW each)	44

The circumferential voltage U_0 required to replace the synchrotron radiation losses per turn at a beam energy E is given approximately by:

$$U_0[\mathrm{eV}] = 28.6 * E^4[\mathrm{GeV}]$$

At 104.5 GeV the two counter rotating beams lose 3.4 GeV per turn, corresponding to 3.2 % of their energy.

Gradient distribution for different Energies

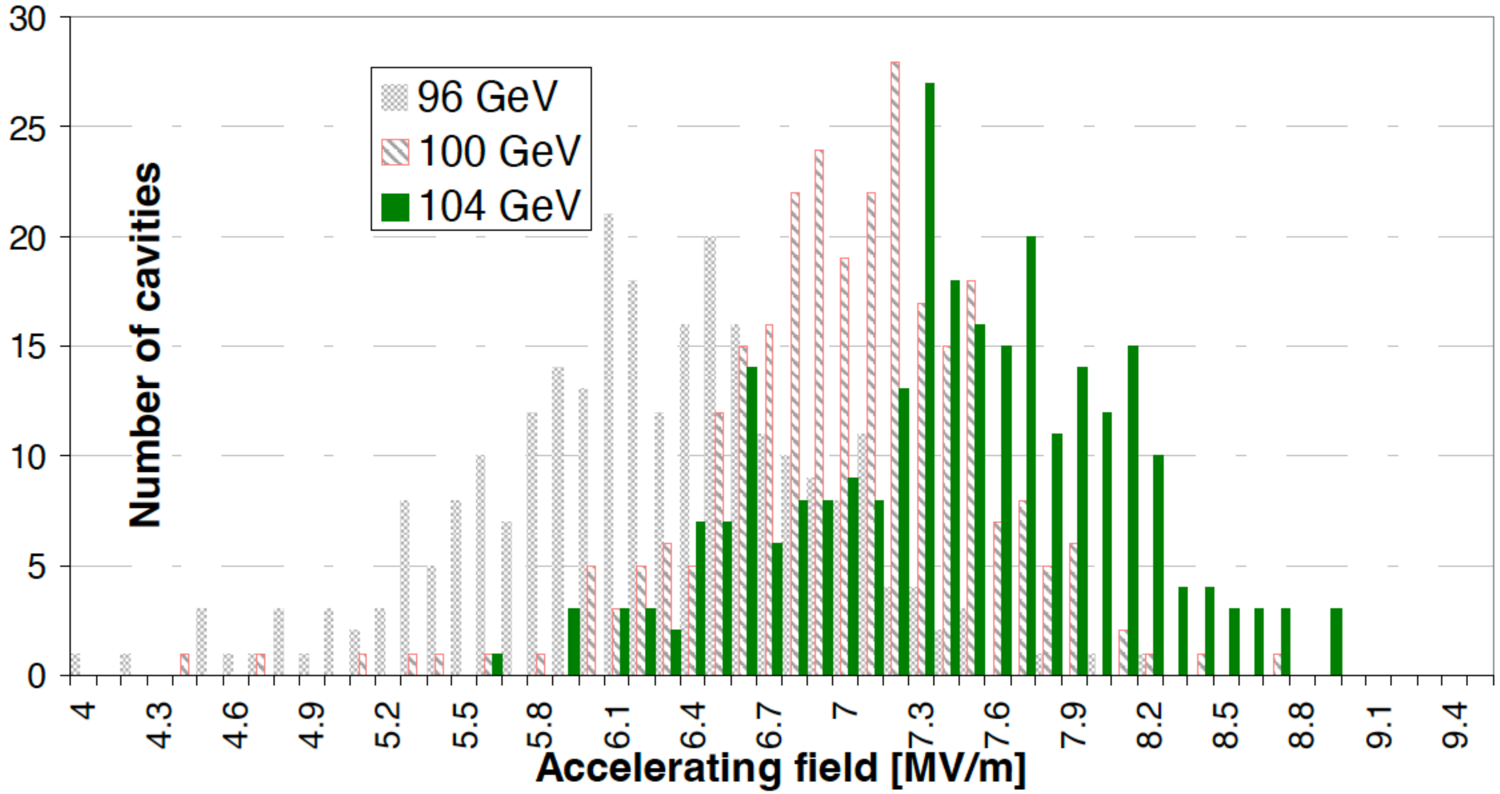
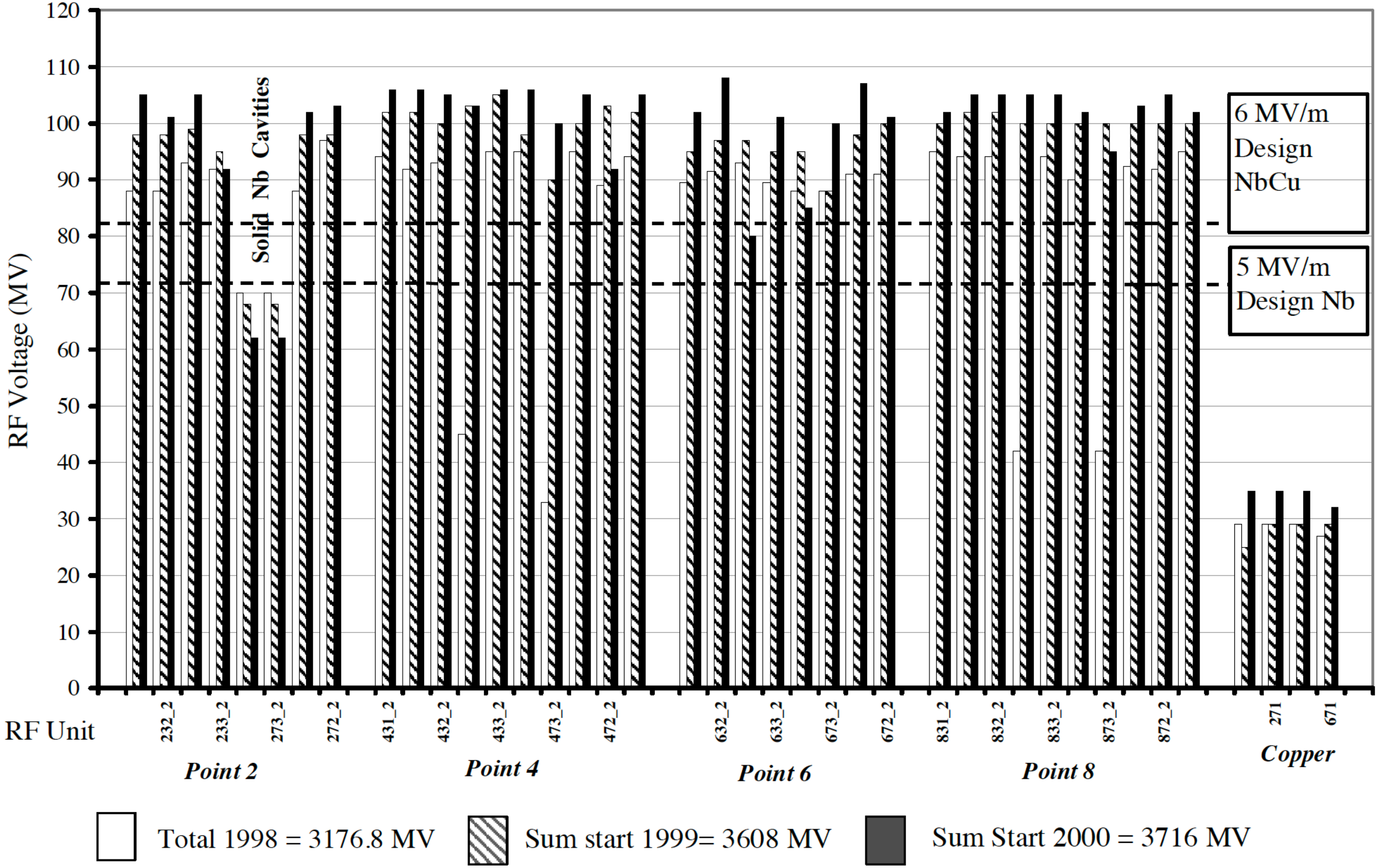


Figure 3.: Histogram of cavity gradient distribution for three different maximum beam energies in 1999 and 2000.

RF unit voltage in 1998,1999 & 2000



Critical Trip Rate at Maximum Energy

The 10th Workshop on RF Superconductivity, 2001, Tsukuba, Japan

OPERATING EXPERIENCE WITH THE LEP2 SUPERCONDUCTING RF SYSTEM

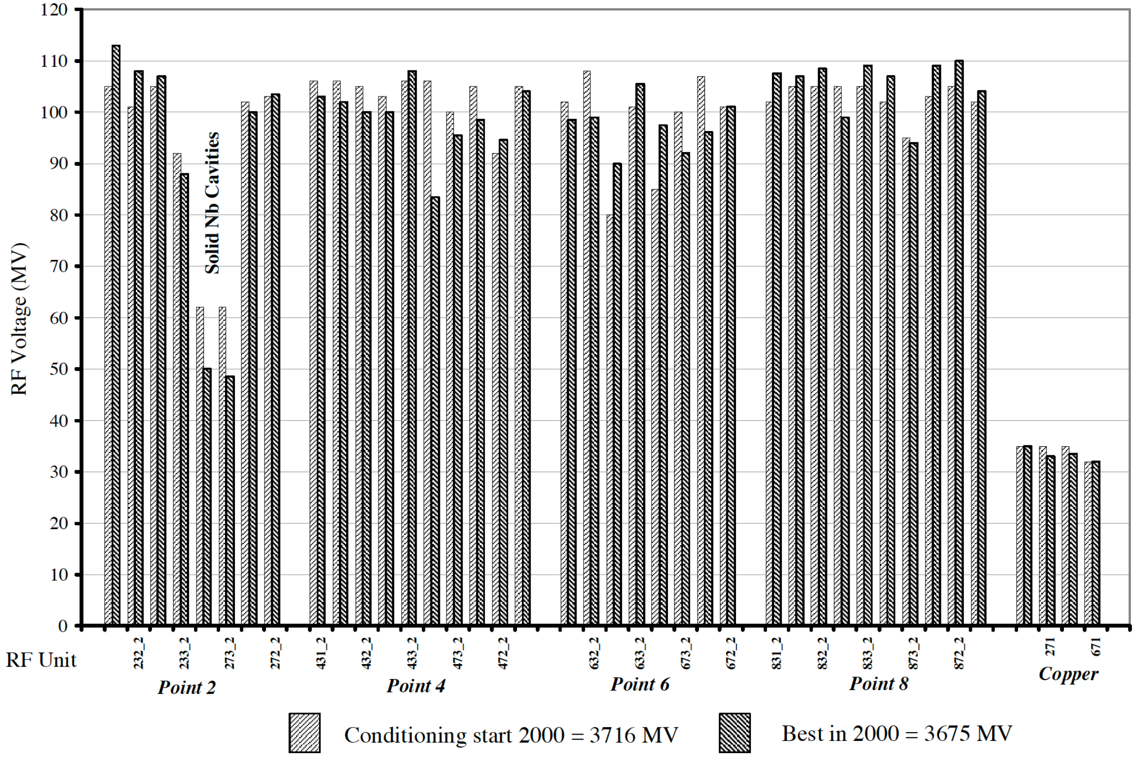


Figure 13: RF voltage distribution on 6th Sept. 2000 compared to maximum levels gained during conditioning.

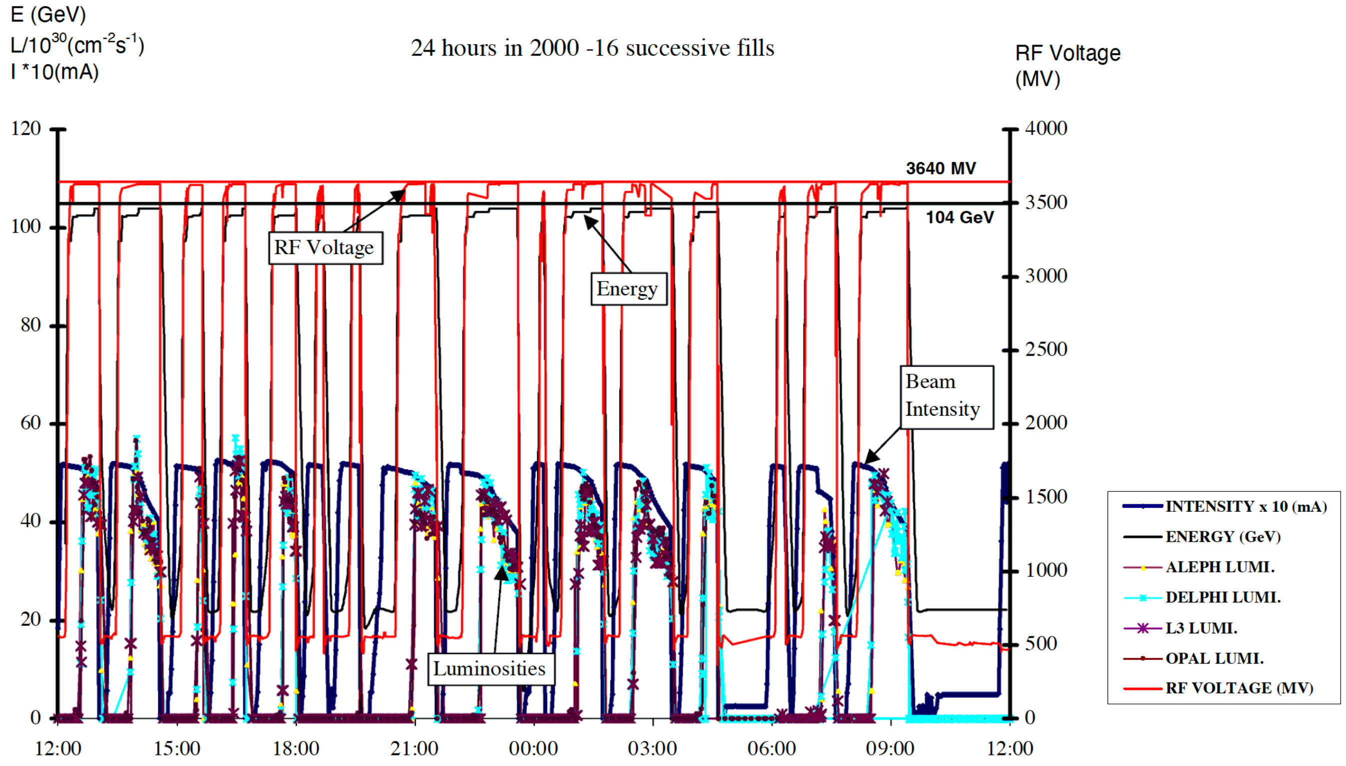
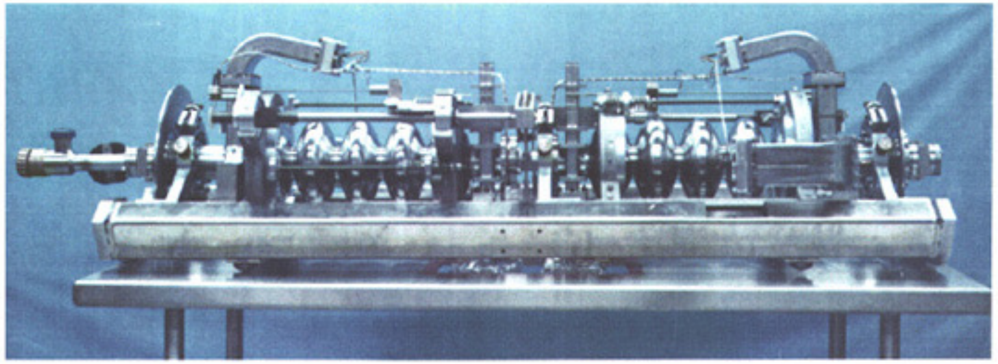


Figure 6: LEP operation over 24 hours in 2000.

CEBAF at TJNAF from 1996

A pair of 5-cell 1.5 GHz cavities (from Cornell)



Aerial view of the CEBAF site

CEBAF important achievements

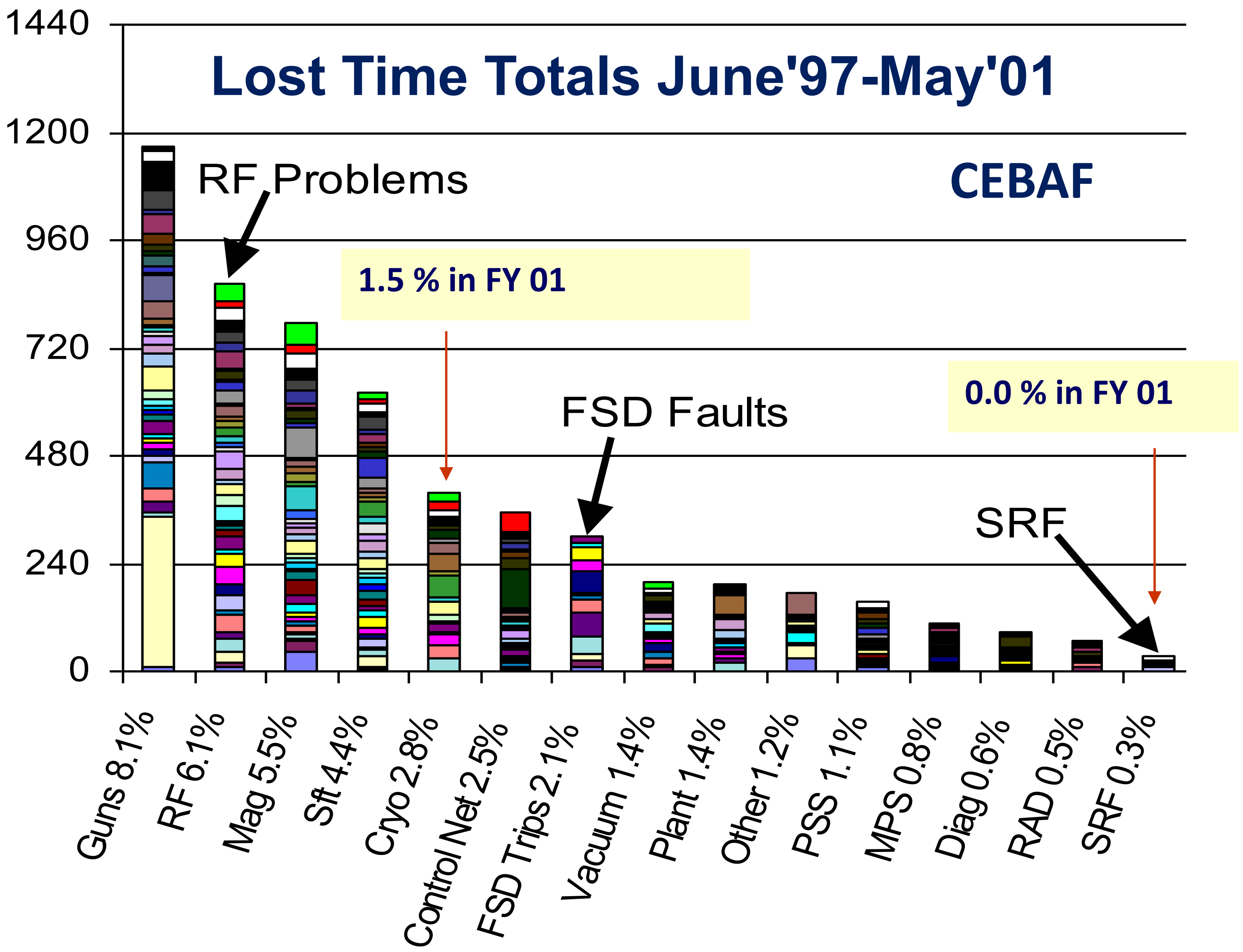
- First large recirculating linac
- Large cryogenic plant at 2 K
- R&D on fabrication and treatments for Nb
- Large plants for preparation and RF tests
- Great experience on SRF linac operation
- Excellent SRF reliability demonstrated
- Set the background for SNS

SRF Test Infrastructure at Jefferson Lab

Lessons learned from CEBAF from 1996

- Processing and conditioning improve cavity performances, when not limited by material defects (hard quench)
- **Field emission moves to higher field**
- **Accelerating Field improves with time**
- 2 K operation very reliable and well understood
- All ancillaries perform quite well
- Maximum energy and beam current above the design values
- CEBAF **performances finally limited by the installed cryo-power and RF-power**

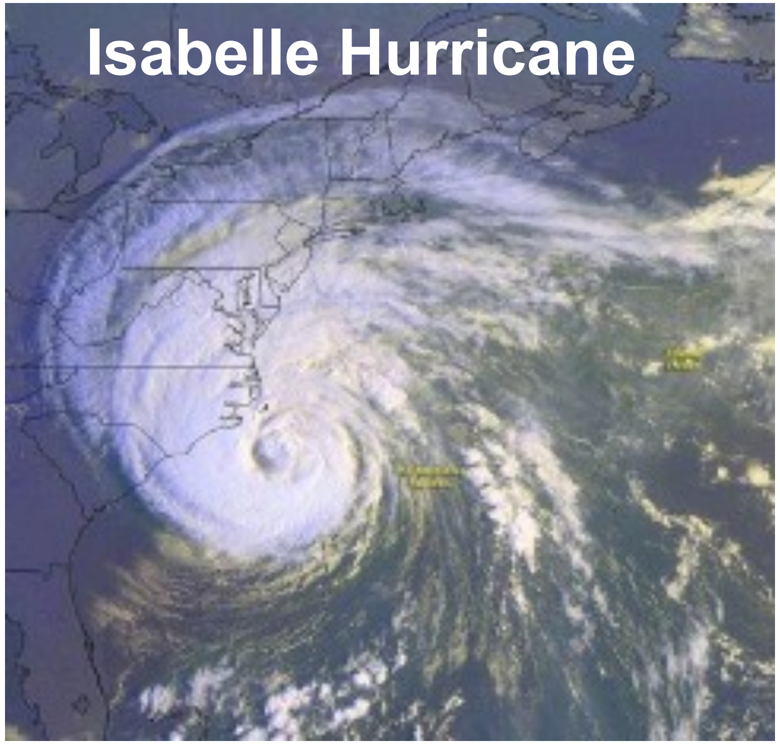
A great success for CEBAF



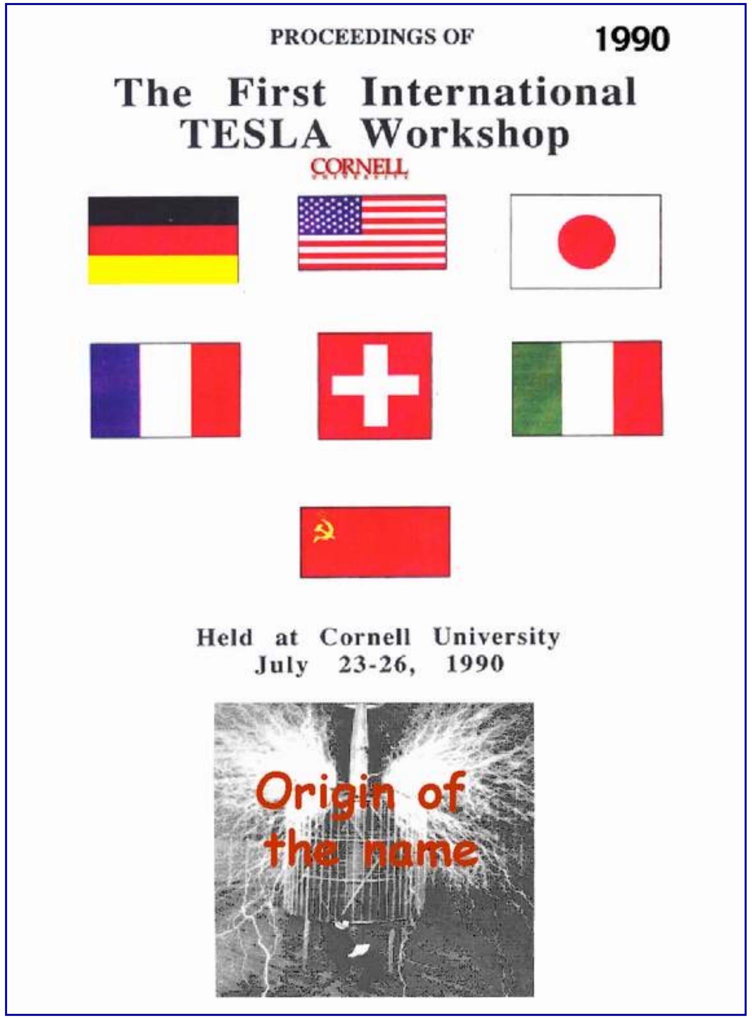
Excellent reliability of SRF technology

High availability for physics

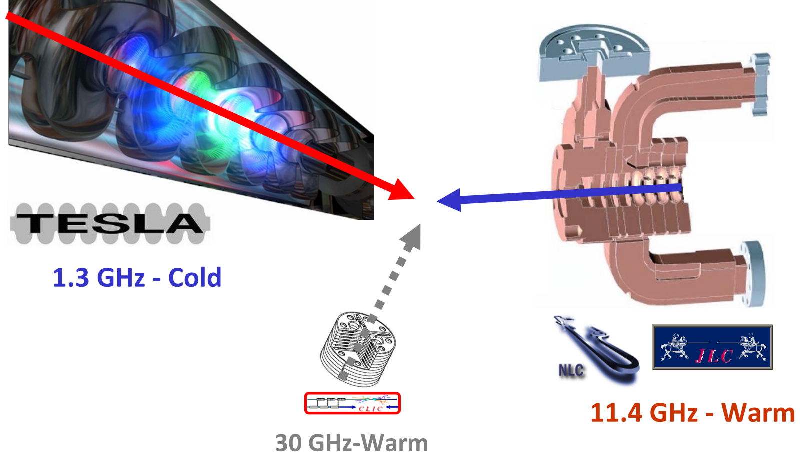
The only warm-up for the



1990: and so… TESLA for next Linear Collider



Competing Technologies



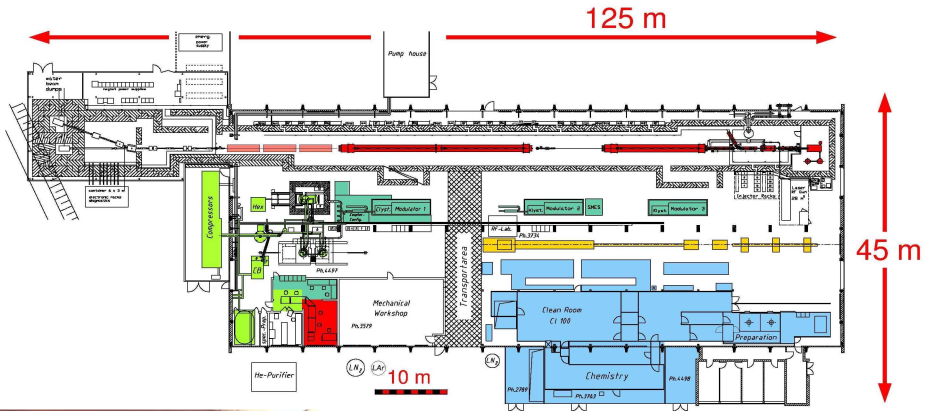
Basic goals to be reached

- **Increase gradient by a factor of 5**
  (Physical limit for Nb at ~ 50 MV/m)
- **Reduce cost per MV by a factor 20**
  (New cryomodule concept and Industrialization)
- **Make possible pulsed operation**
  (Combine SRF and mechanical engineering)

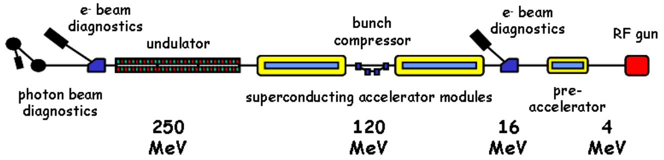
Advantages of SRF vs NC

- **Higher conversion efficiency**:
  more beam power for less plug power consumption
- **Lower RF frequency**:
  relaxed tolerances and smaller emittance dilution

The path to a new SRF standard with BCP



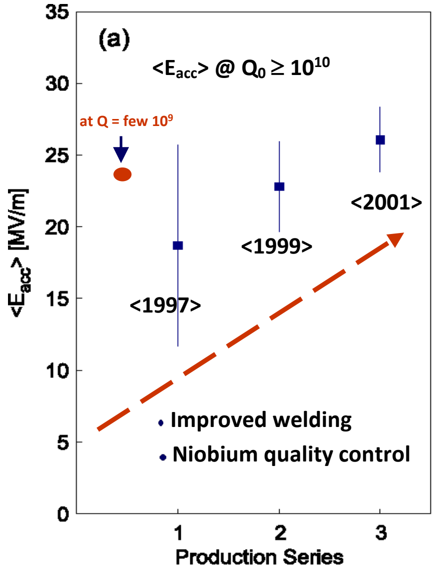
TTF as operated for SASE FEL

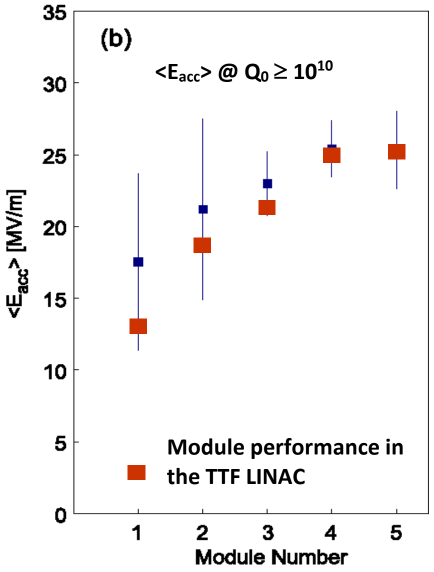


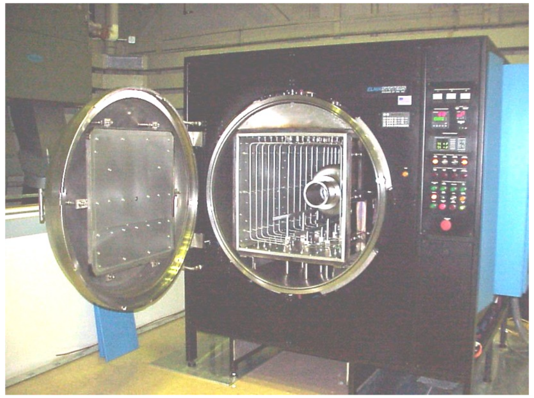
3 cavity productions from 4 European industries: Accel, Cerca, Dornier, Zanon

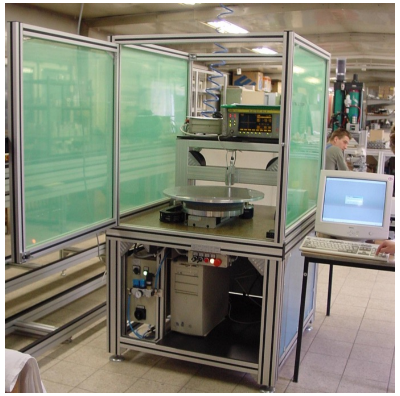
Cornell 1995

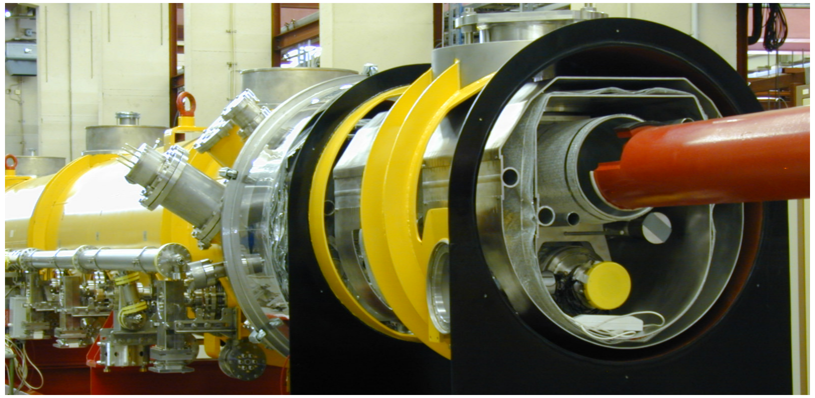
5-cell







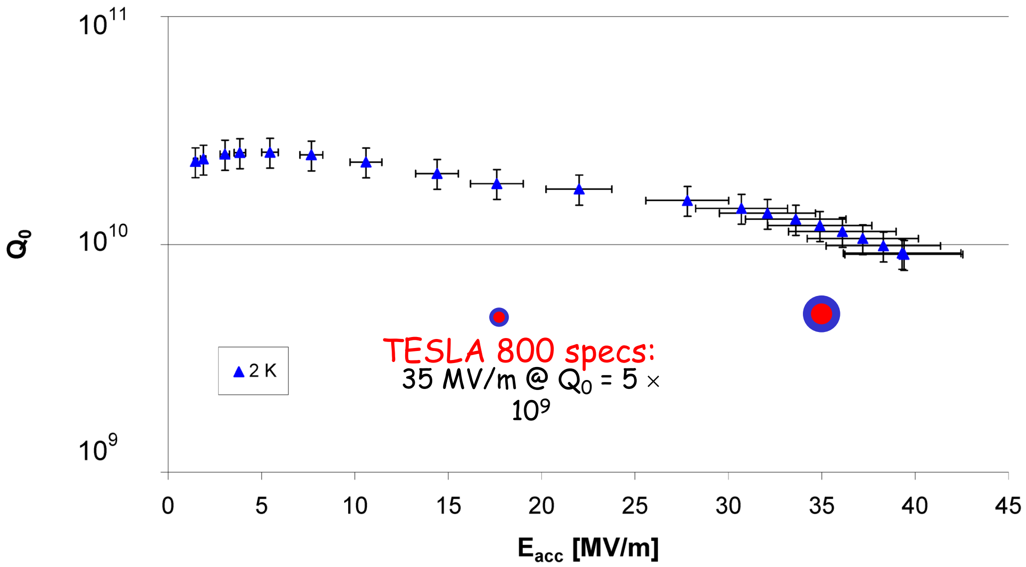


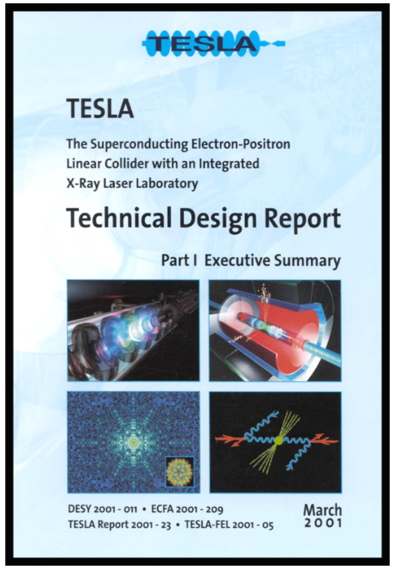


From BCP to TESLA TDR and EuXFEL

Electro-Polishing (EP)
from KEK (**Kenji Saito**)

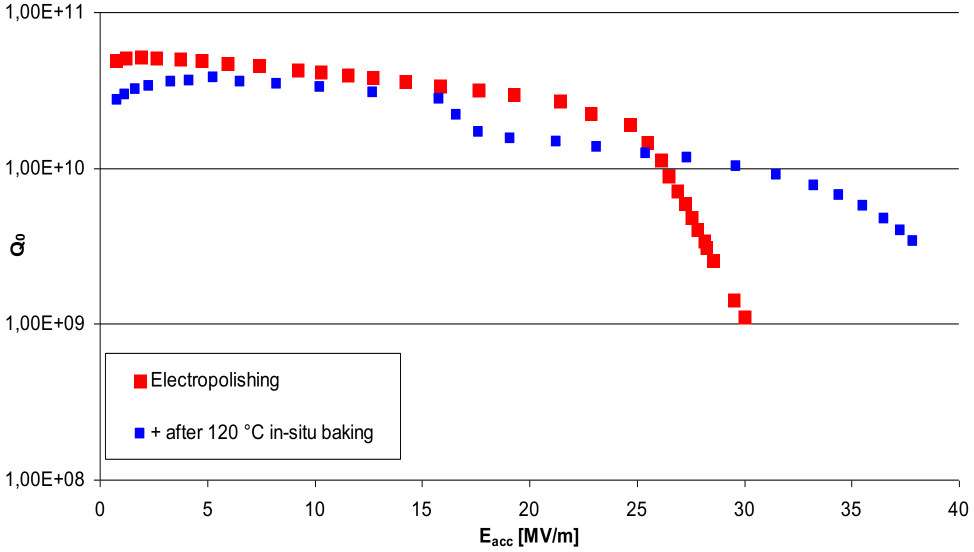
Improves surface and cleaning





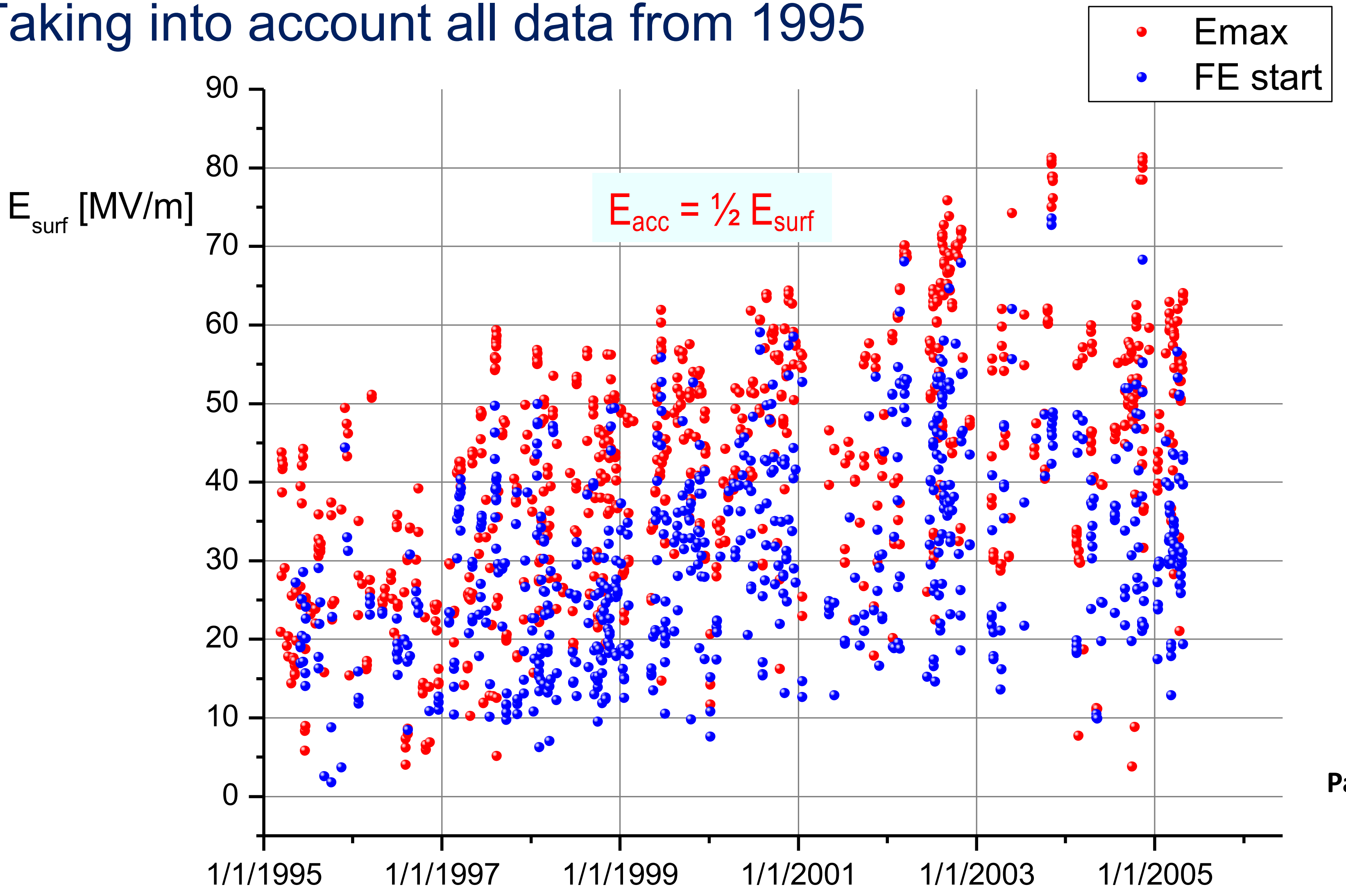
In-Situ Baking (120-140 °C)
from CEA-Saclay (**B. Visentin**)

Cures Q-drop at High Field



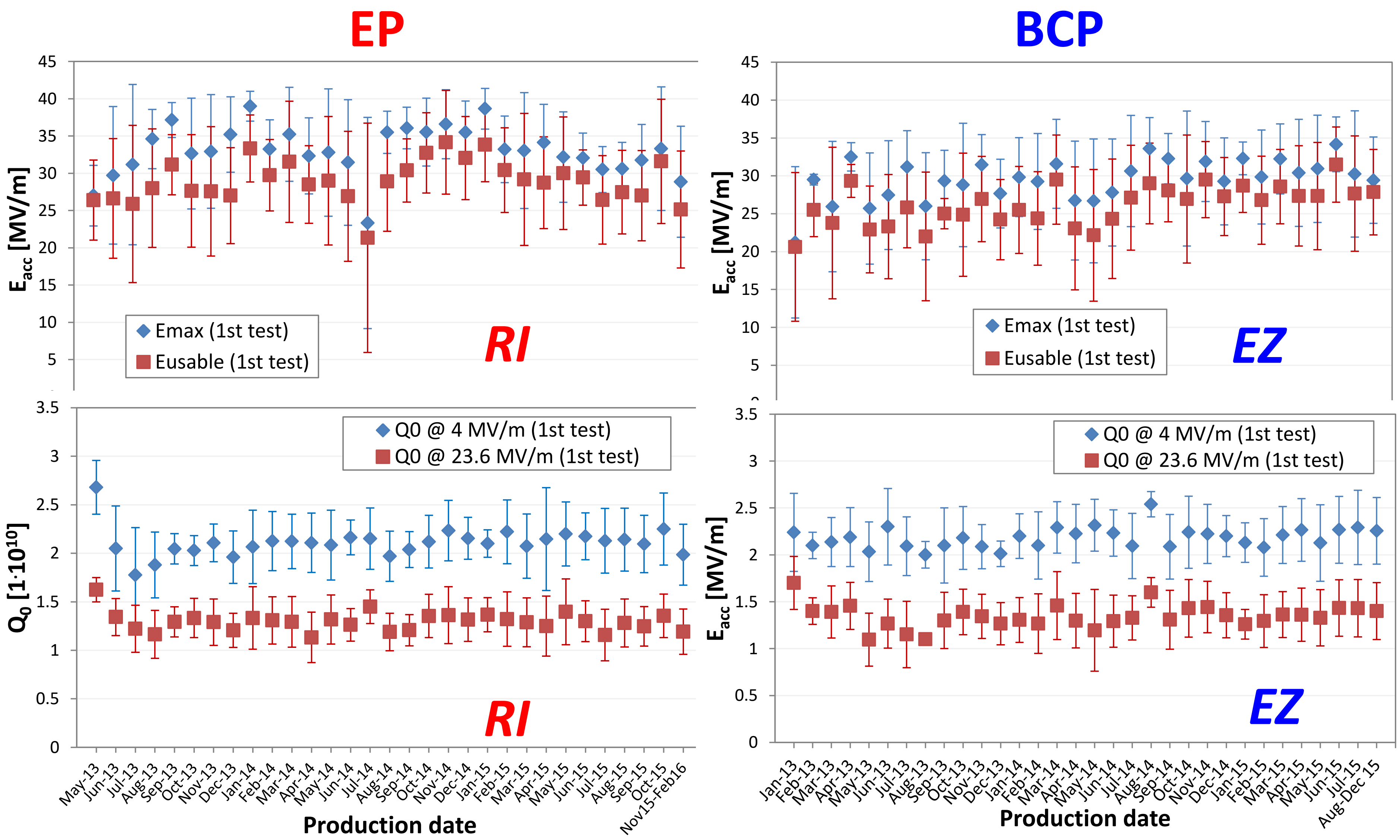
10 years of experience with TTF before EuXFEL

Taking into account all data from 1995



Paolo Pierini

EuXFEL, VT of 800 cavities «as received»

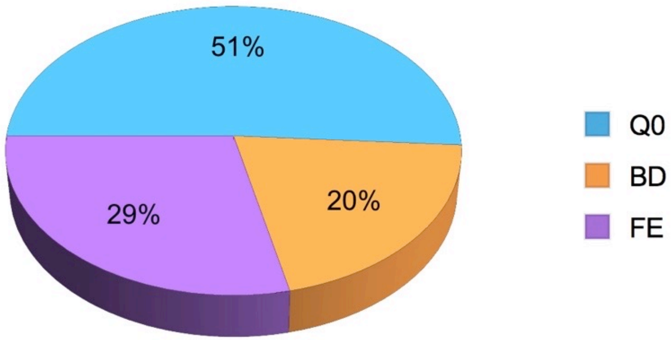


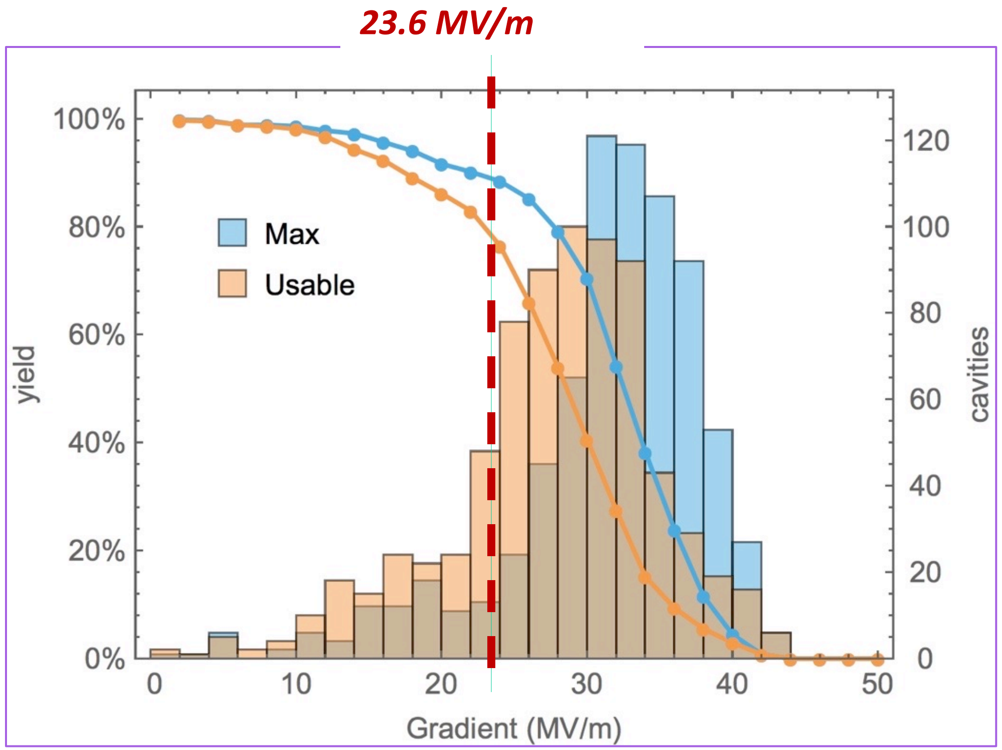
EuXFEL cavities: as received Usable Gradien

Include operations spec

- $Q_0 \geq 1\times10^{10}$
- FE threshold (X-ray)

→ **Usable Gradient**

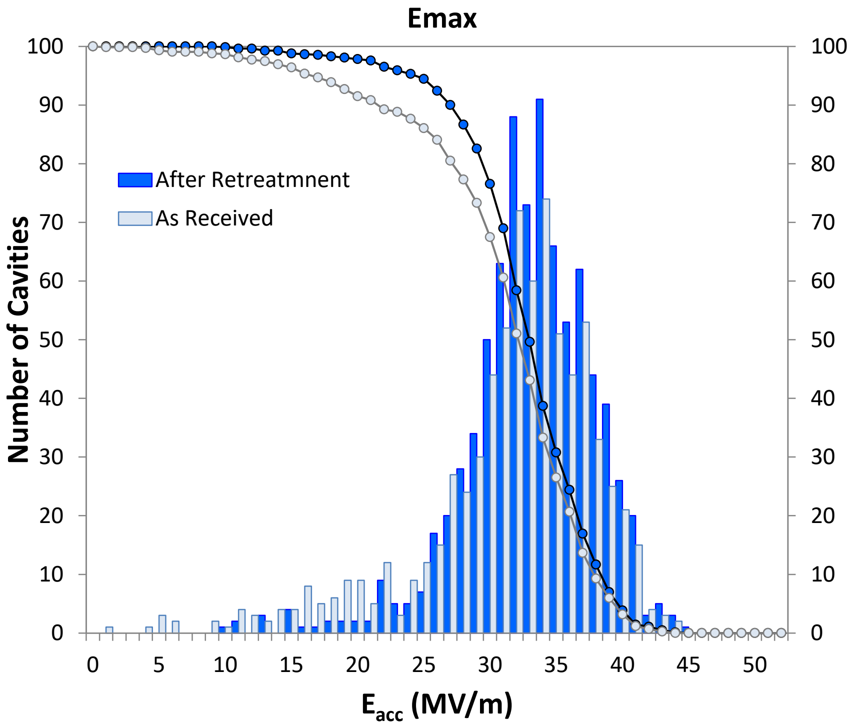


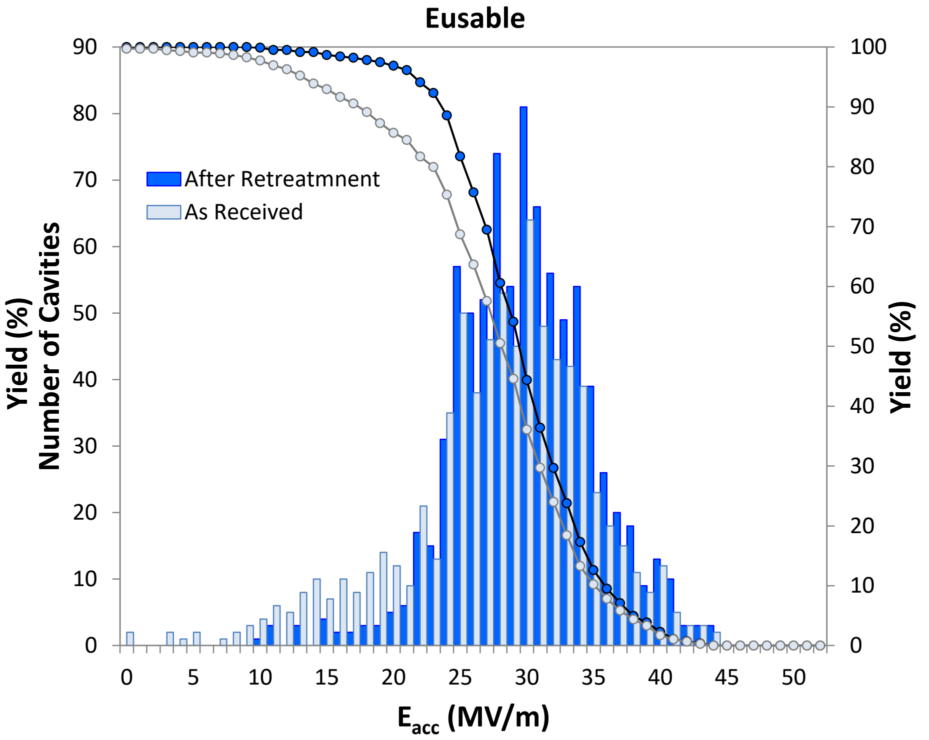


		Max	Usable
Average	MV/m	31.4	27.7
RMS	MV/m	6.8	7.2
Median (50%)	MV/m	32.5	28.7
Yield ≥20 MV/m		92%	86%
Yield ≥26 MV/m		85%	66%

EuXFEL cavities: final performance: Eacc

Total after 313 retreatments performed on 237 of the 831 cavities





Before:

E max 31.4 ± 6.8 [MV/m]

(RI): E max 33.0 ± 6.5 [MV/m])

(EZ): E max 29.8 ± 6.6 [MV/m])

After:

E max 33.0 ± 4.8 [MV/m]

(RI): E max 34.7 ± 4.4 [MV/m])

(EZ): E max 31.5 ± 4.9 [MV/m])

Before:

E usable 27.7 ± 7.2 [MV/m]

(RI): E usable 29.0 ± 7.3 [MV/m])

(EZ): E usable 26.4 ± 6.6 [MV/m])

After:

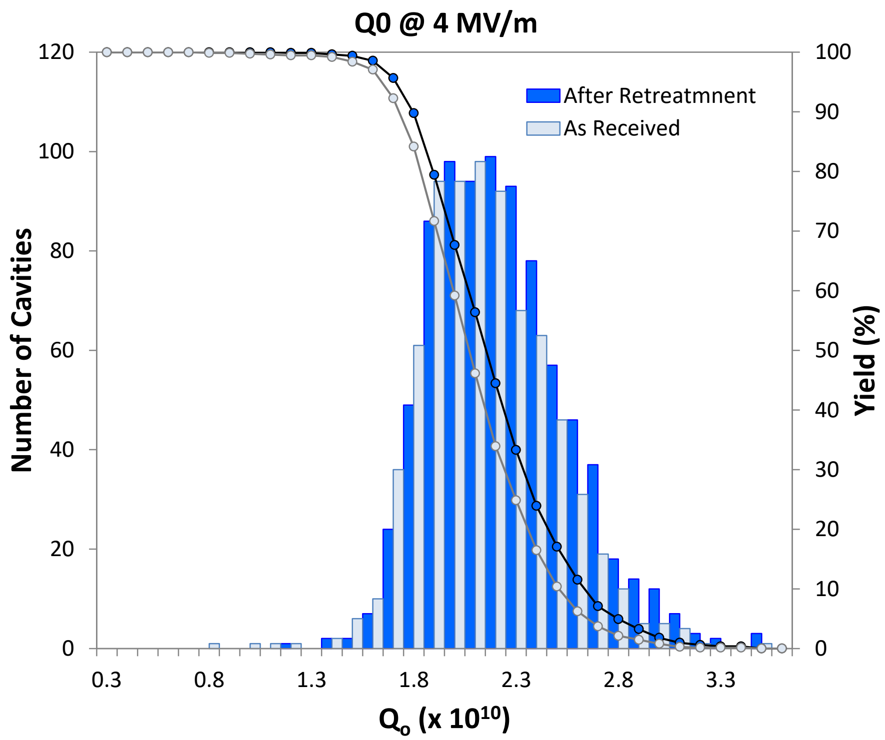
E usable 29.8 ± 5.1 [MV/m]

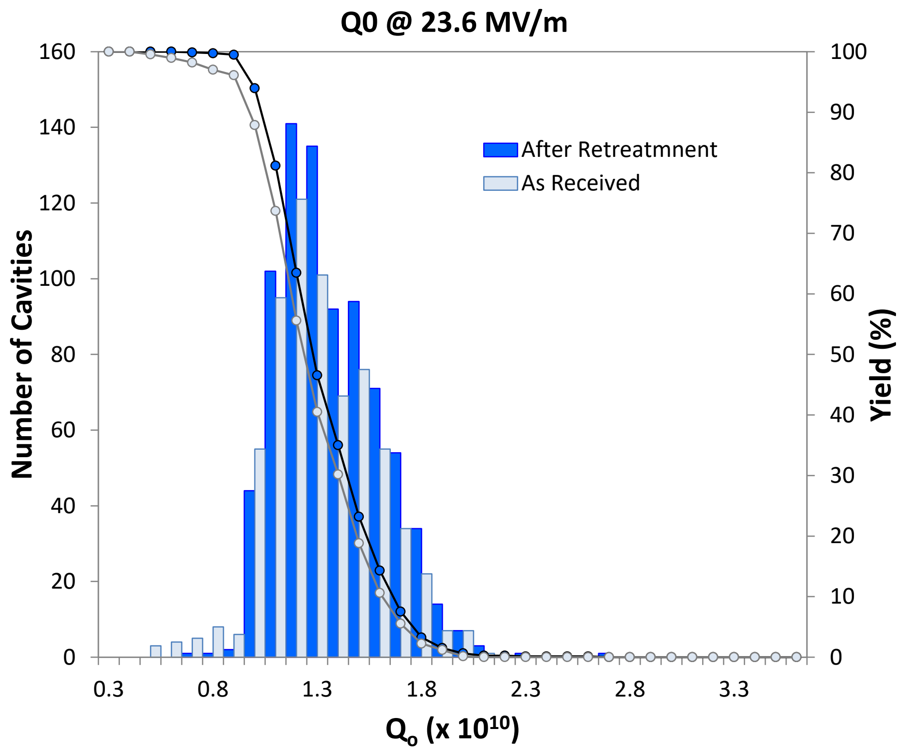
(RI): E usable 31.2 ± 5.2 [MV/m])

(EZ): E usable 28.6 ± 4.8 [MV/m])

EuXFEL cavities: final performance: Q_0

Total after 313 retreatments performed on 237 of the 831 cavities





Before :

Q0 @ 4 MV/m 2.15 ± 0.32 [$1 \cdot 10^{10}$]

(RI): Q0 @ 4 MV/m 2.11 ± 0.32 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 4 MV/m 2.18 ± 0.32 [$1 \cdot 10^{10}$])

After:

Q0 @ 4 MV/m 2.23 ± 0.34 [$1 \cdot 10^{10}$]

(RI): Q0 @ 4 MV/m 2.21 ± 0.34 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 4 MV/m 2.26 ± 0.33 [$1 \cdot 10^{10}$])

Before:

Q0 @ 23.6 MV/m 1.31 ± 0.26 [$1 \cdot 10^{10}$]

(RI): Q0 @ 23.6 MV/m 1.29 ± 0.24 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 23.6 MV/m 1.34 ± 0.28 [$1 \cdot 10^{10}$])

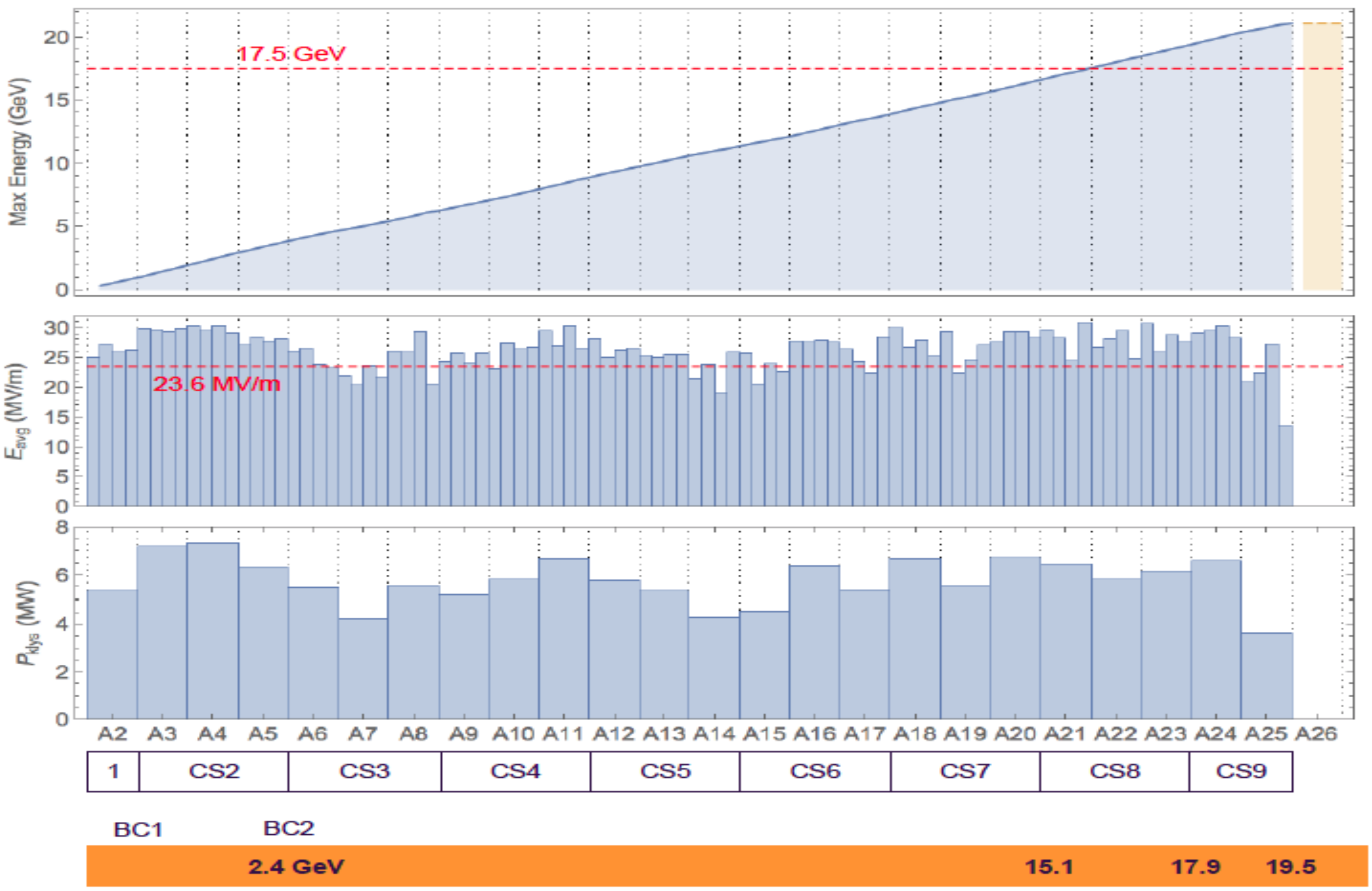
After:

Q0 @ 23.6 MV/m 1.37 ± 0.25 [$1 \cdot 10^{10}$]

(RI): Q0 @ 23.6 MV/m 1.34 ± 0.22 [$1 \cdot 10^{10}$])

(EZ): Q0 @ 23.6 MV/m 1.41 ± 0.26 [$1 \cdot 10^{10}$])

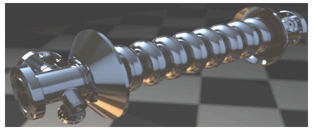
EuXFEL: Usable Installed Voltage



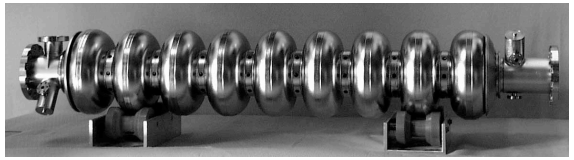
Some of the elliptical (TM) cavities

for electrons, and protons (ions) with b ≥ 0.5

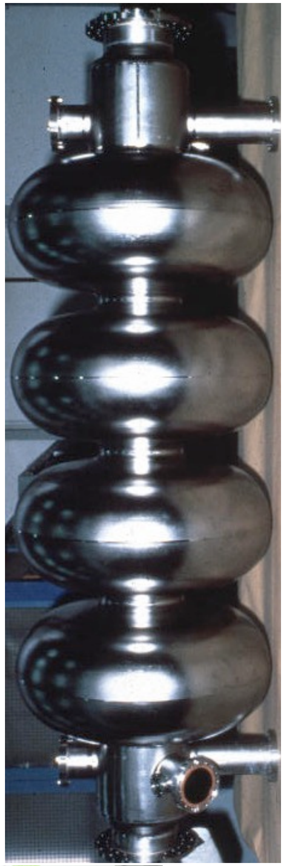
FLASH/XFEL 3.9 GHz



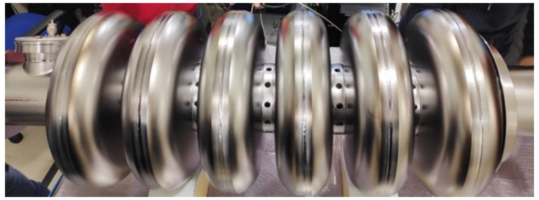
TESLA/XFEL/ILC 1.3 GHz



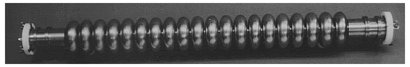
LEP 352 MHz
Nb bulk prototype



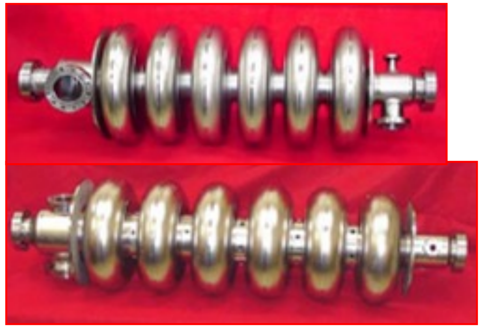
ESS 704 MHz (ß=0.67)



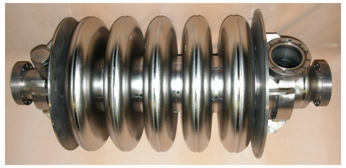
S-DALINAC 3 GHz



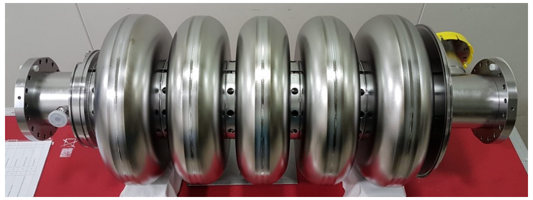
SNS 805 MHz (ß=0.61&0.81)



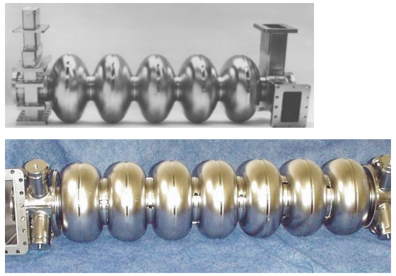
TRASCO 704 MHz (ß=0.47)



PIP-II 650 MHz (ß=0.61)

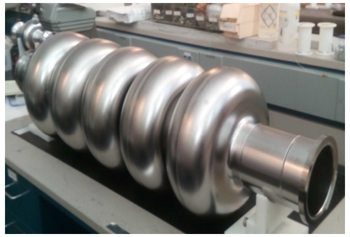


CEBAF 1.5 GHz

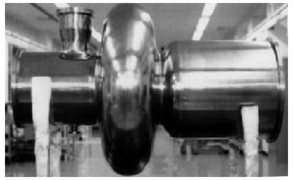


RHIC e cooling 704 MHz

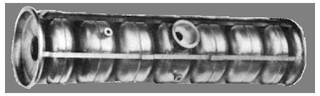
FCCee 800 MHz



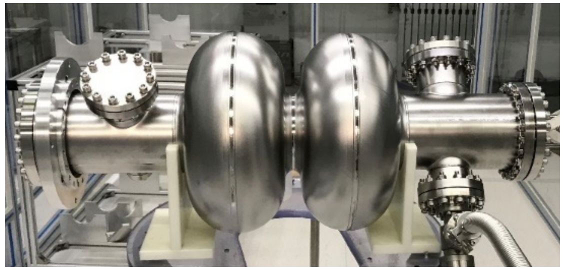
KEK-B 500 MHz



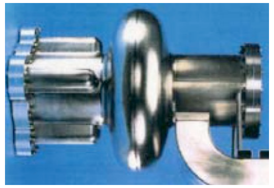
HEPL 1.3 GHz



CEPC 650 MHz



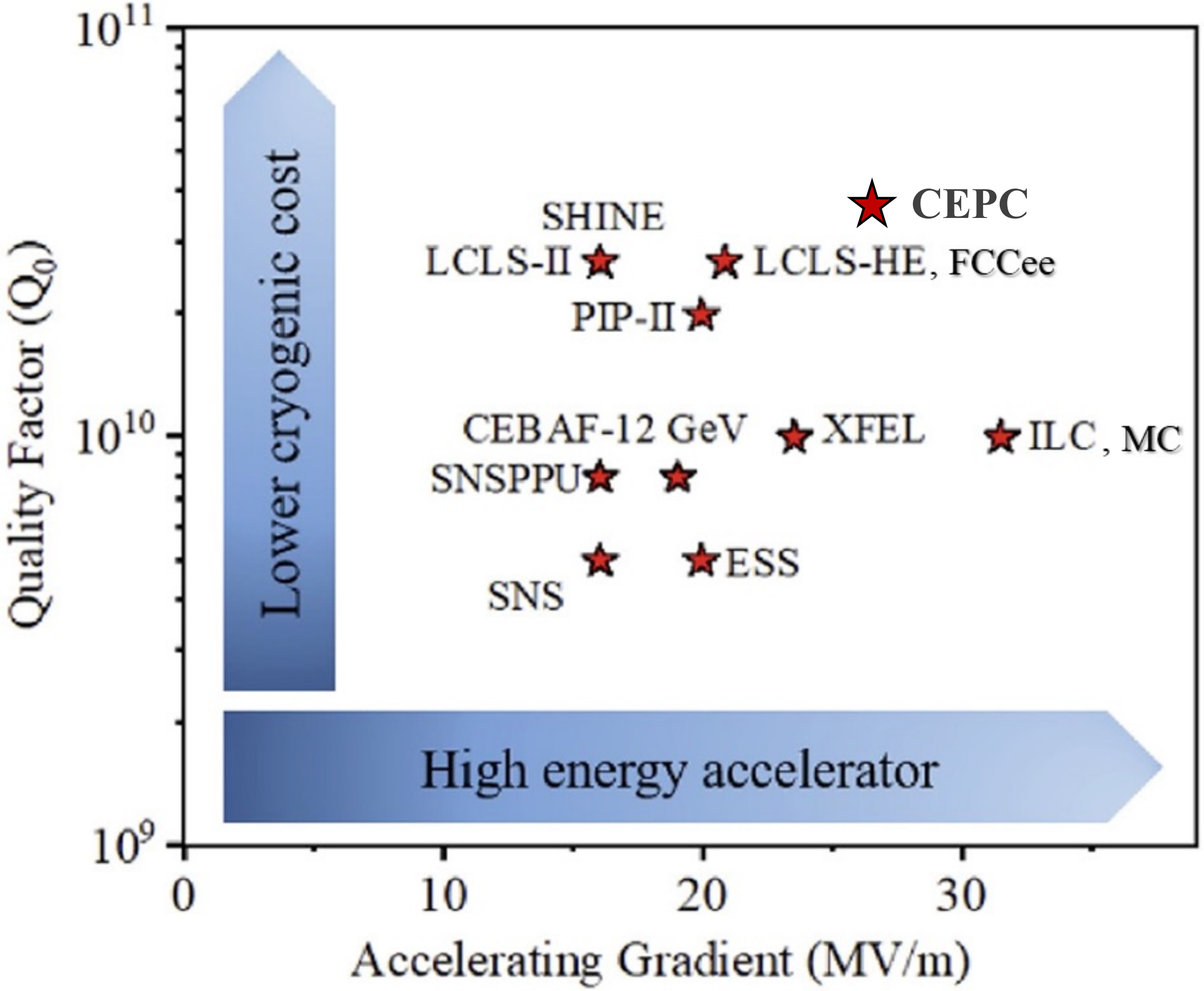
CESR 500 MHz



HERA 500 MHz

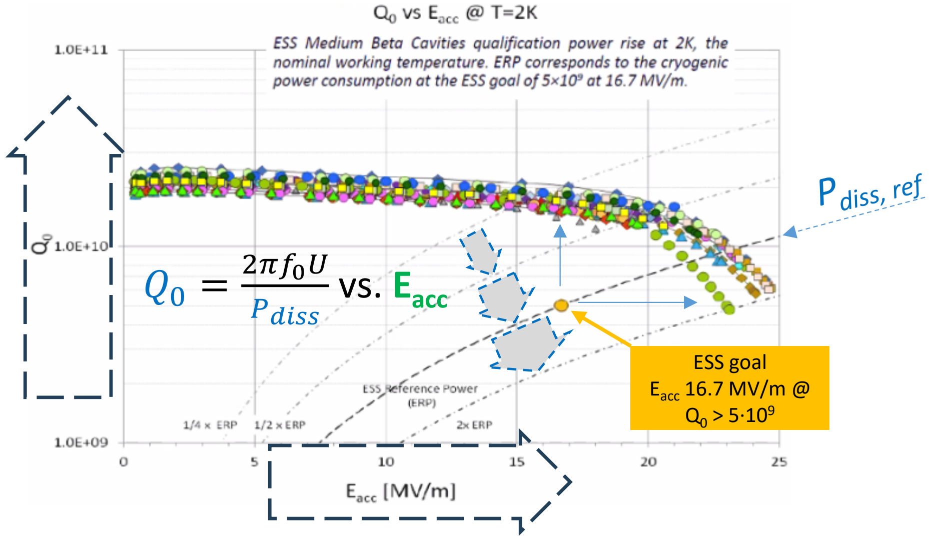
TRISTAN 508 MHz

Expected Q_0 & G in new Projects



Example of high Q_0 & high E_{acc}

(ESS, 704.4 MHz, β=0.67)



9-cell 1.3 GHz cavity

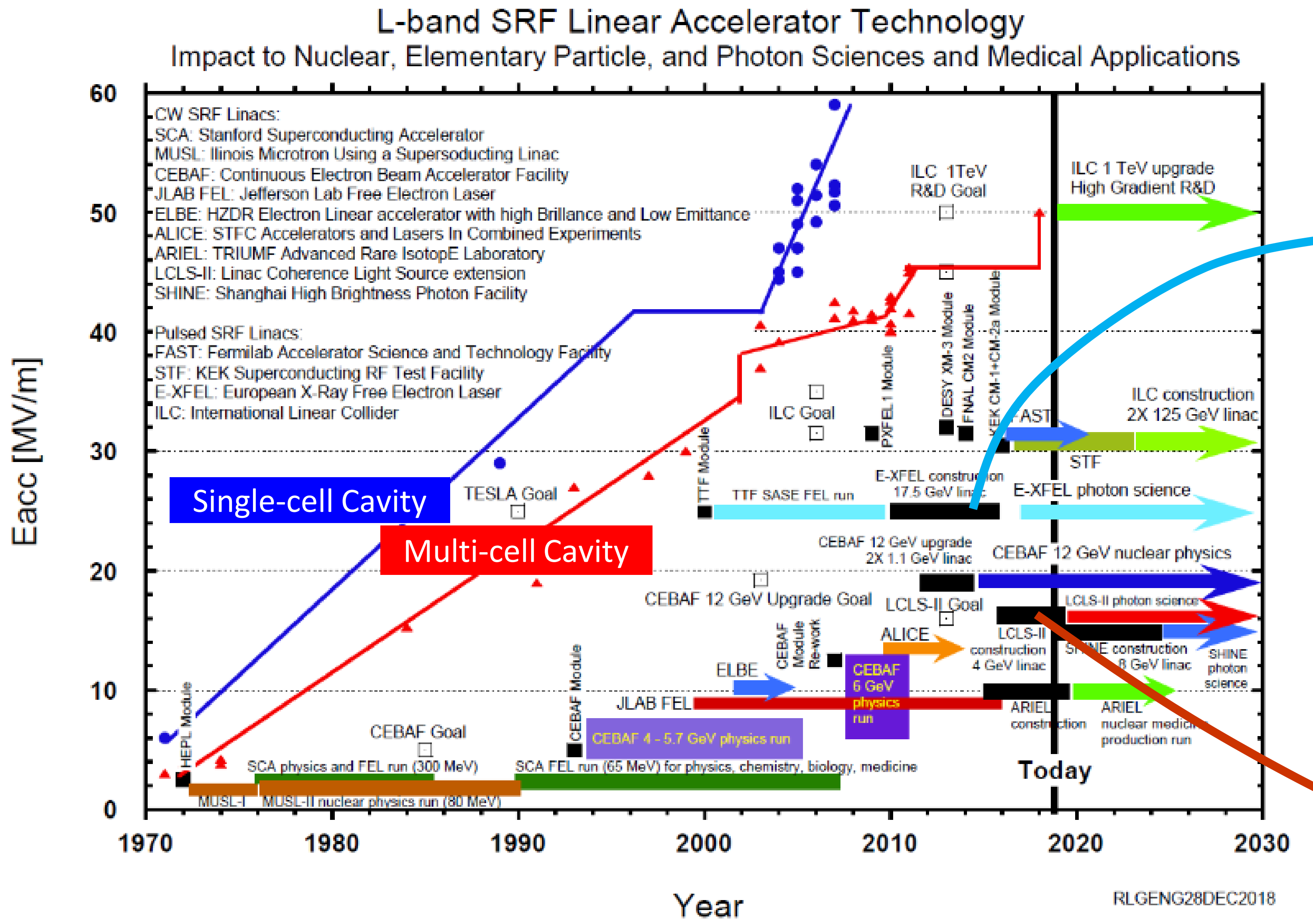
Cavity qualification goal (vertical test) typically 10% higher w.r.t operational goal

As an example, for ILC:

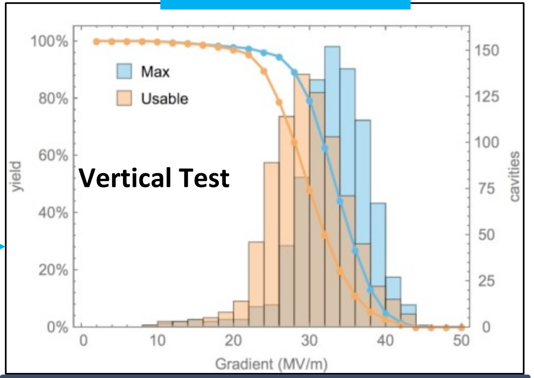
- **E_{acc} = 35 MV/m @ Q_0 ≥** $0.8\cdot10^{10}$ **(qualification)**
- **E_{acc} = 31.5 MV/m @ Q_0 ≥** $1\cdot10^{10}$ (operational)

A Picture from Rongli Geng, 28 Dec. 2018

R&D results vs time & Large Machines



E-XFEL



Final Performances

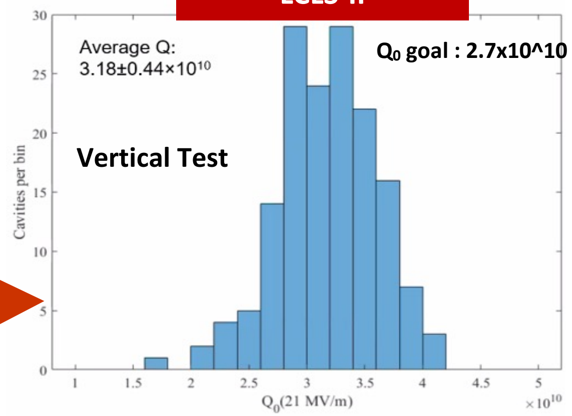
E_{max} = 33.0 ±4.8 [MV/m]

E_{usable} = 29.8 ±5.1 [MV/m]

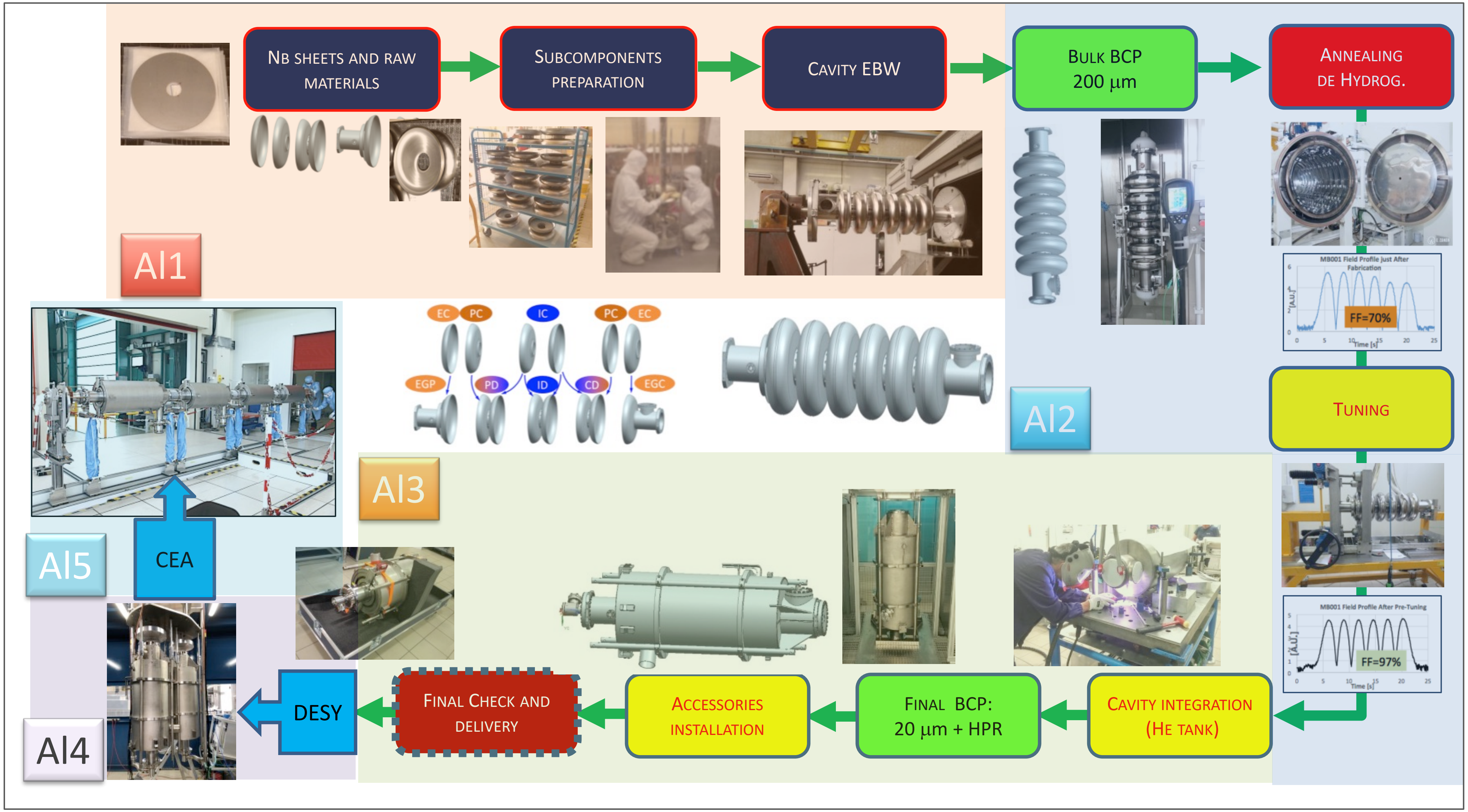
Q_0 (23.6MV/m) = 1.4 ±0.2 [10^{10}]

(E_{goal} = 23.6 [MV/m], $Q_0 \geq 1 \cdot 10^{10}$)

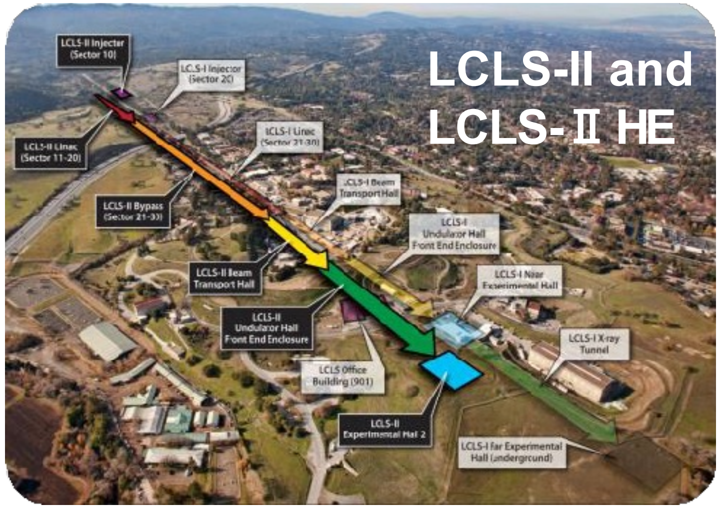
LCLS-II

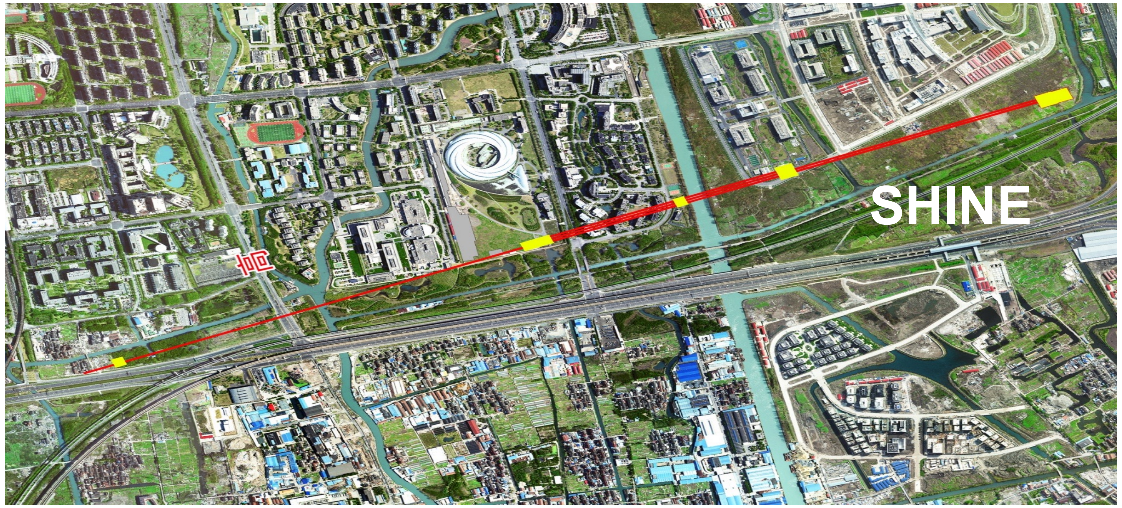


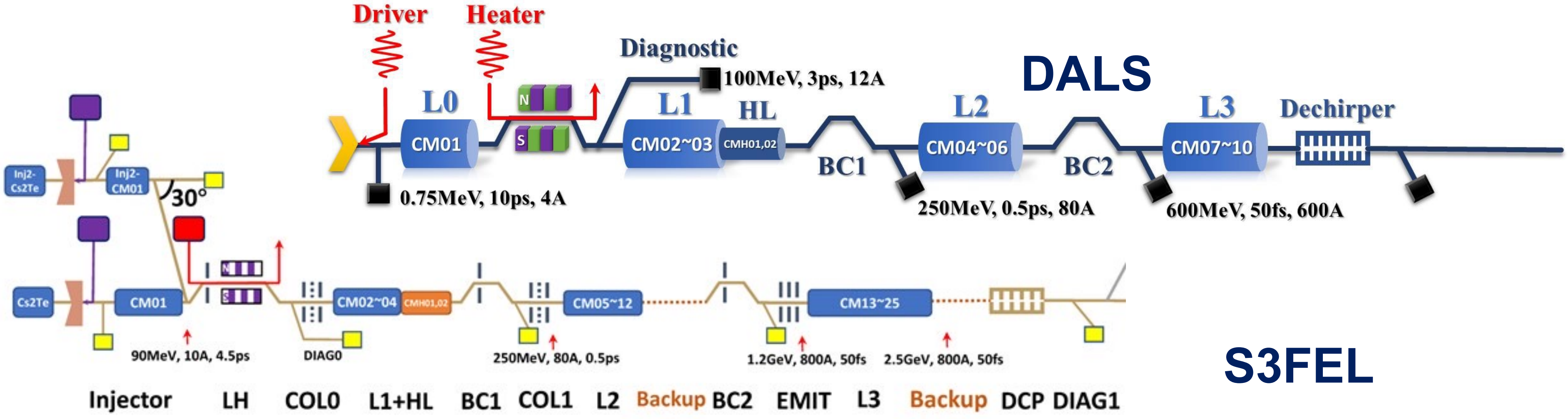
Flow Chard of one β=0.61 ESS Cavity



New CW XFELs from TESLA Technology

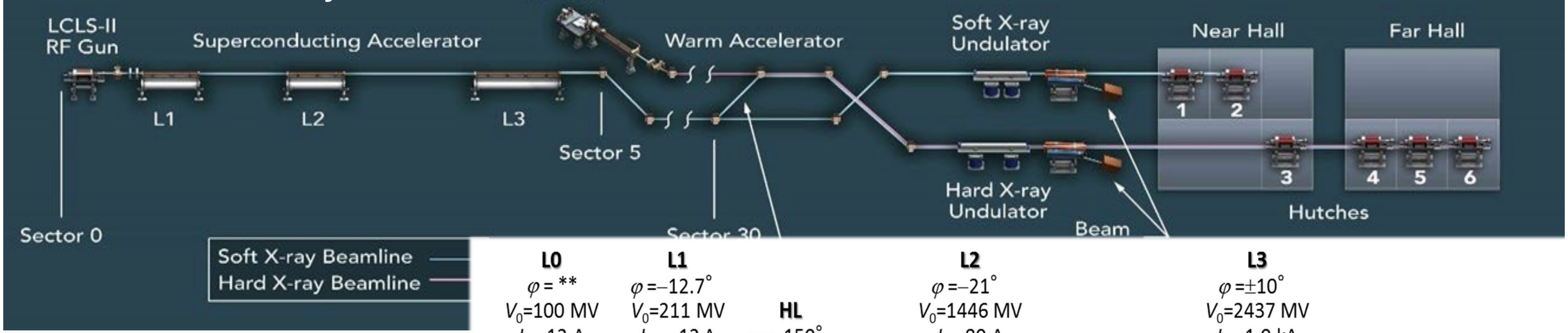


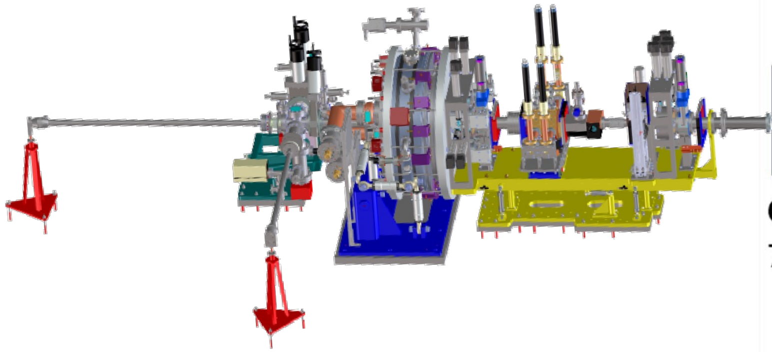


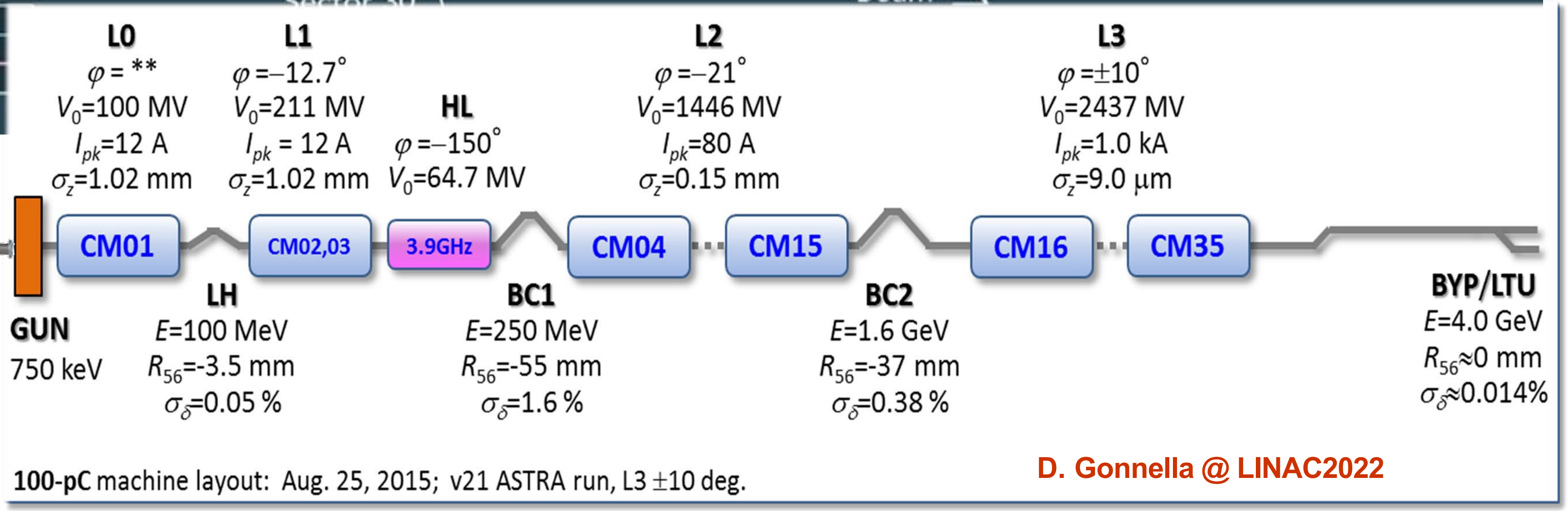


LCLS-II: the present State of the Art wt N-doping

- RF Photocathode Gun
- 35 1.3 GHz Cryomodules
- 2 3.9 GHz Cryomodules







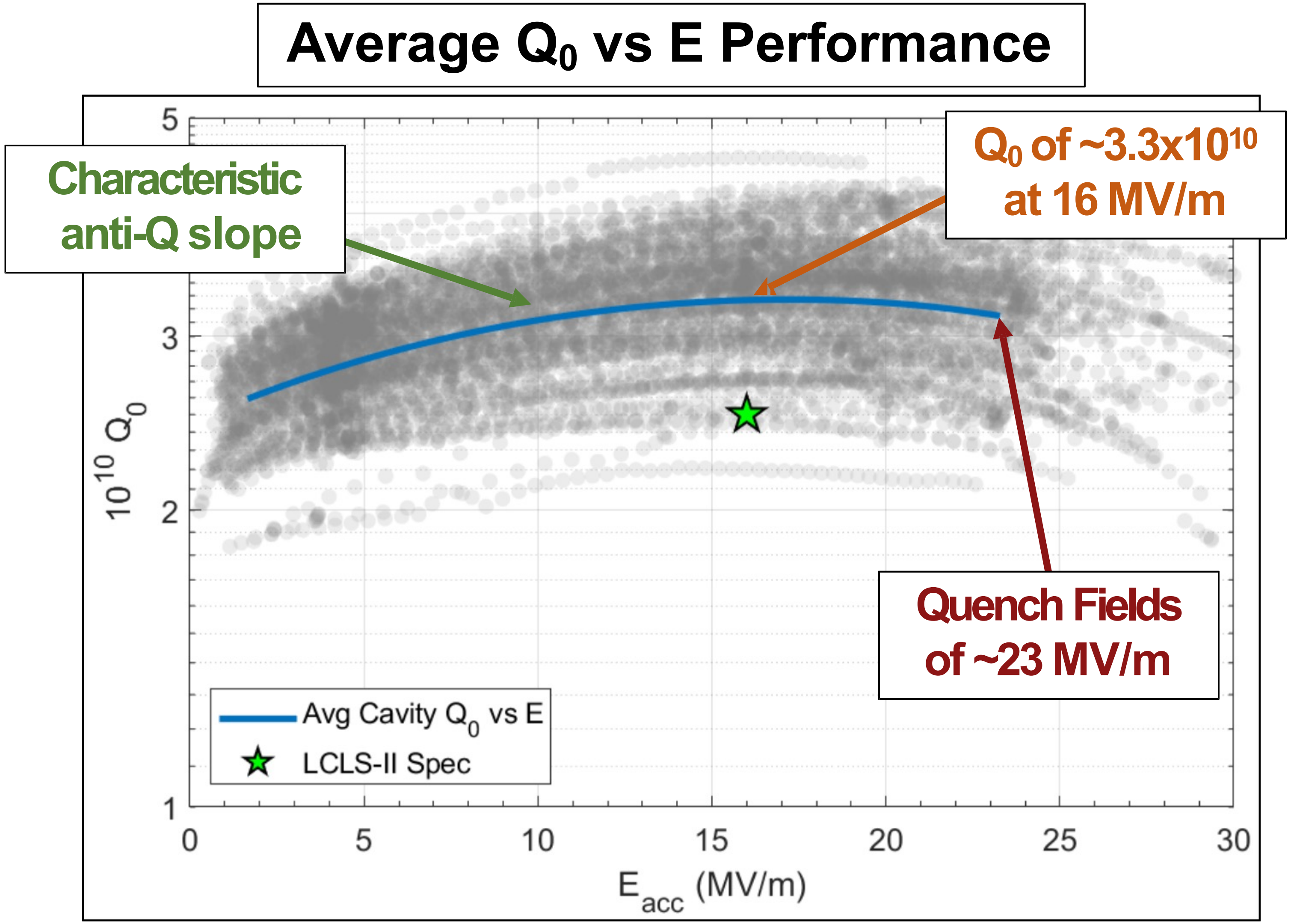
D. Gonnella @ LINAC2022

LCLS-II Technical Parameters

Performance Measure	Threshold	Objective
Variable gap undulators	2 (soft and hard x-ray)	2 (soft and hard x-ray)
Superconducting linac-based FEL system		
Superconducting linac electron beam energy	3.5 GeV	≥ 4 GeV
Electron bunch repetition rate	93 kHz	929 kHz
Superconducting linac charge per bunch	0.02 nC	0.1 nC
Photon beam energy range	250–3,800 eV	200–5,000 eV
High repetition rate capable end stations	≥ 1	≥ 2
FEL photon quantity (10^{-3} BW) per bunch	5×10^8 (10x spontaneous) @2,500 eV	> 10^{11} @ 3,800 eV
Normal conducting linac-based system		
Normal conducting linac electron beam energy	13.6 GeV	15 GeV
Electron bunch repetition rate	120 Hz	120 Hz
Normal conducting linac charge per bunch	0.1 nC	0.25 nC
Photon beam energy range	1–15 keV	1–25k eV
Low repetition rate capable end stations	≥ 2	≥ 3
FEL photon quantity (10^{-3} BW[a]) per bunch	10^{10} (lasing @ 15 keV)	> 10^{12} @ 15 keV

D. Gonnella @ LINAC2022

Nitrogen-Doping for LCLS-II



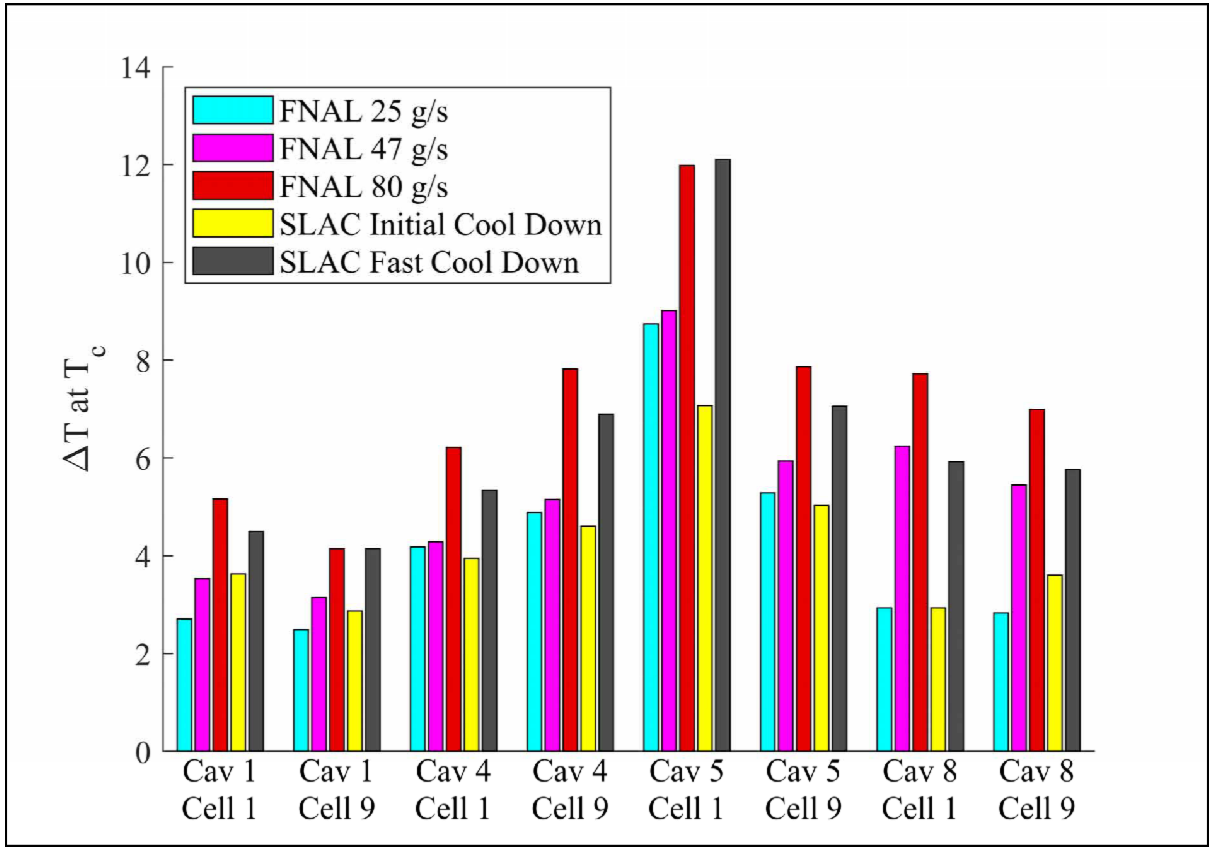
- LCLS-II constructed 373 nitrogen- doped 1.3 GHz cavities
- All cavities were produced with the 2/6 nitrogen-doping protocol
- Significant procedural improvements were made along the way to achieve reliable good performance

  (flux expulsion, fabrication techniques)

D. Gonnella @ SRF2023

Fast Cool Down Results

ΔT at NC/SC Transition



Sufficient cool downs for High Q_0 achieved at SLAC

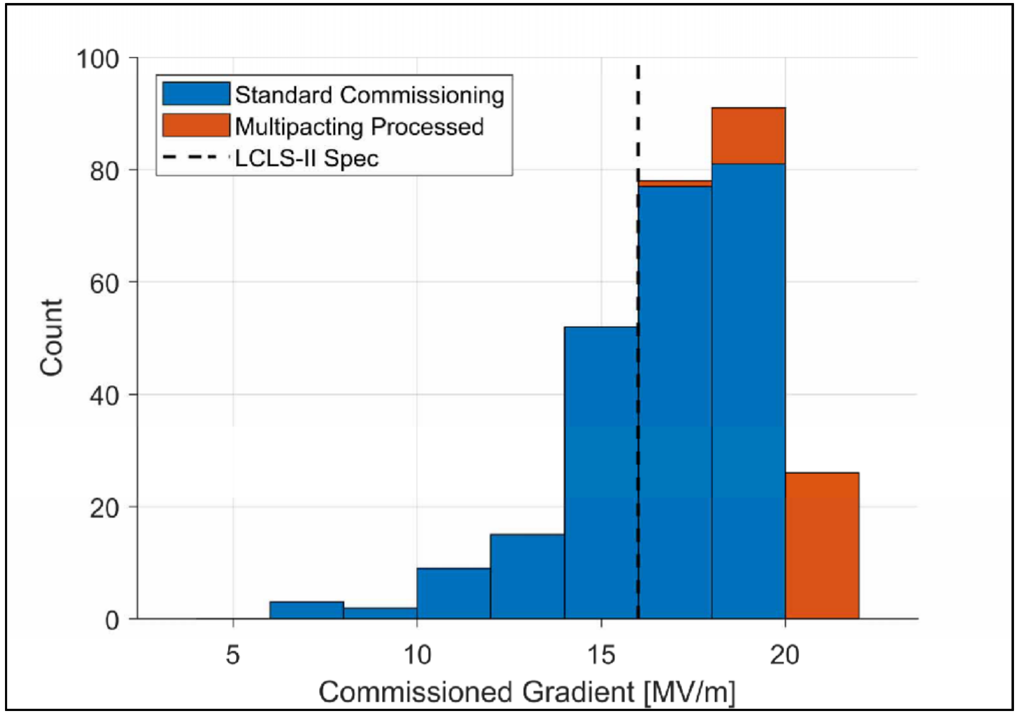
- What we really care about is the cool down *gradient* not the

  rate – faster usually means larger gradients
- Two installed CMs have temperature sensors located on the cavity cells
- Gradients from the SLAC fast cool down and testing at FNAL could be compared to gauge how "successful" we were
- Non-optimized cool down results in lower ΔT than achieved at the test stands
- Fast cool down process produces similar gradients to FNAL CMTF
- We are now able to routinely achieve similar temperature gradients across the cavities to what was achieved during CM testing

D. Gonnella @ SRF2023

Overall SRF Commissioning Status

Gradient Performance

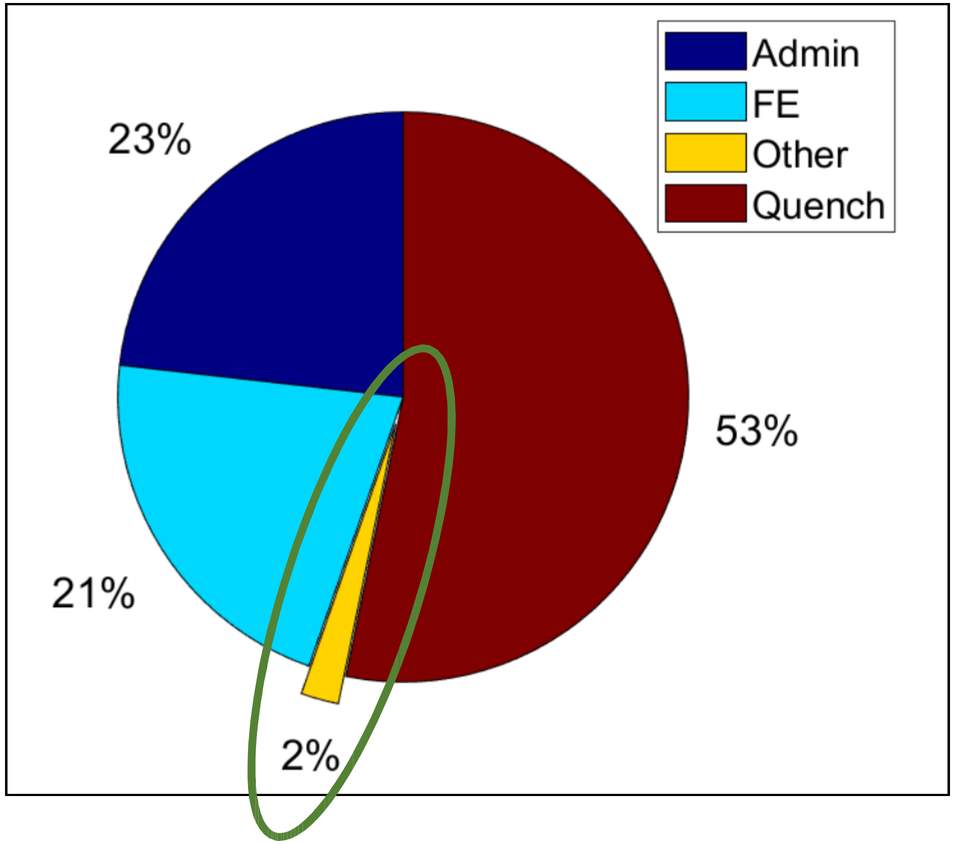


- Cryomodule commissioning has been very successful
- 97% of installed cavities fully operational (planned 94%)
- Majority of testing included an admin limit of 18 MV/m
- Total commissioned voltage exceeds design by >20%

Total Commissioned Cavity Voltage: 4.9 GV

D. Gonnella @ SRF2023

Cavity Limitations

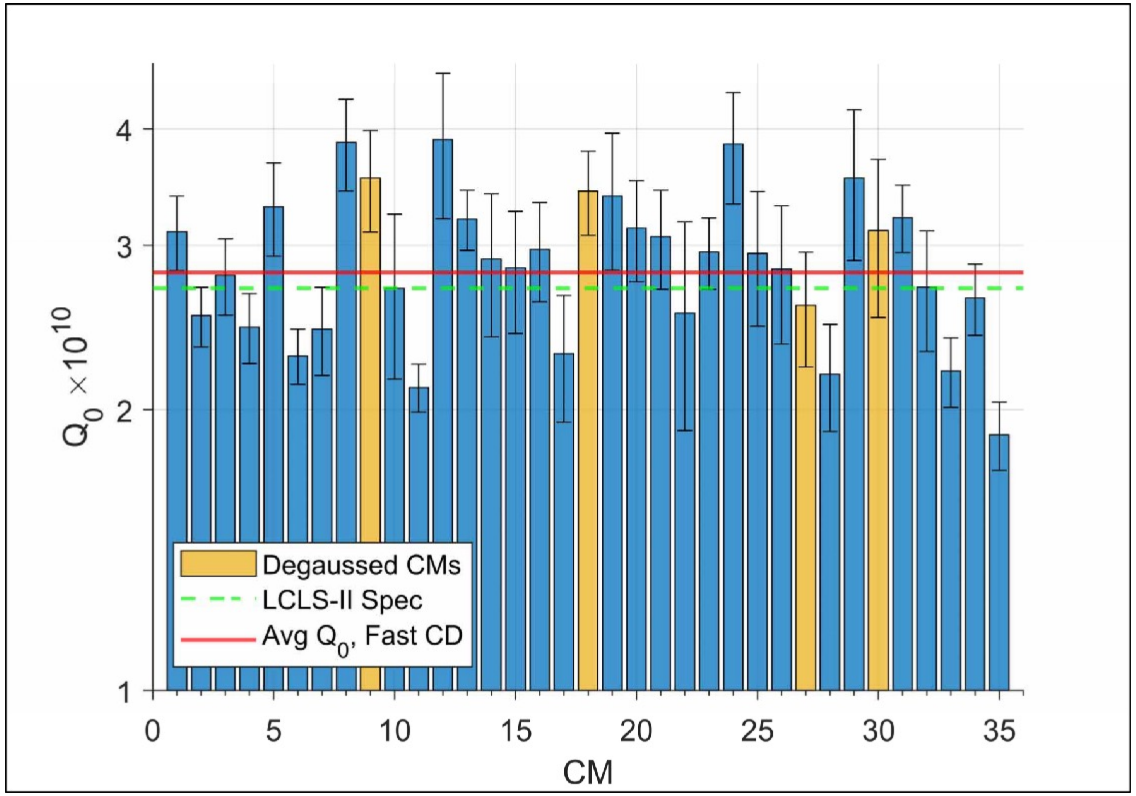


80% of cavities reach ≥16 MV/m

D. Gonnella @ SRF2023

- The majority of cavities were limited by quench below the admin limit of 18 MV/m
  - It is suspected that many of these are limited by multipacting which could be processed
- About one-quarter of the cavities reached the admin limit
- About one-fifth of the cavities were limited by field emission
- The remaining 2% of cavities are unable to be used:
  - 2 cavities: poor contact between coupler warm and cold ends
  - 4 cavities: tuners not functioning properly
  - It is expected that all 6 of these cavities could be repaired *in situ* at room temperature

The Q_0 that was promised…



- Due to the strong coupling in the CM, Q_0 is measured cryogenically
- Full CM average Q_0 results look promising
- Across the linac an average of 2.8×10^{10} has been observed, exceeding the spec of 2.7×10^{10}
- Low performers can likely be improved by additional CM degaussing

Demonstrates High Q_0 in an installed linac for the first time

D. Gonnella @ SRF2023

Cavities Vertical Fest Results

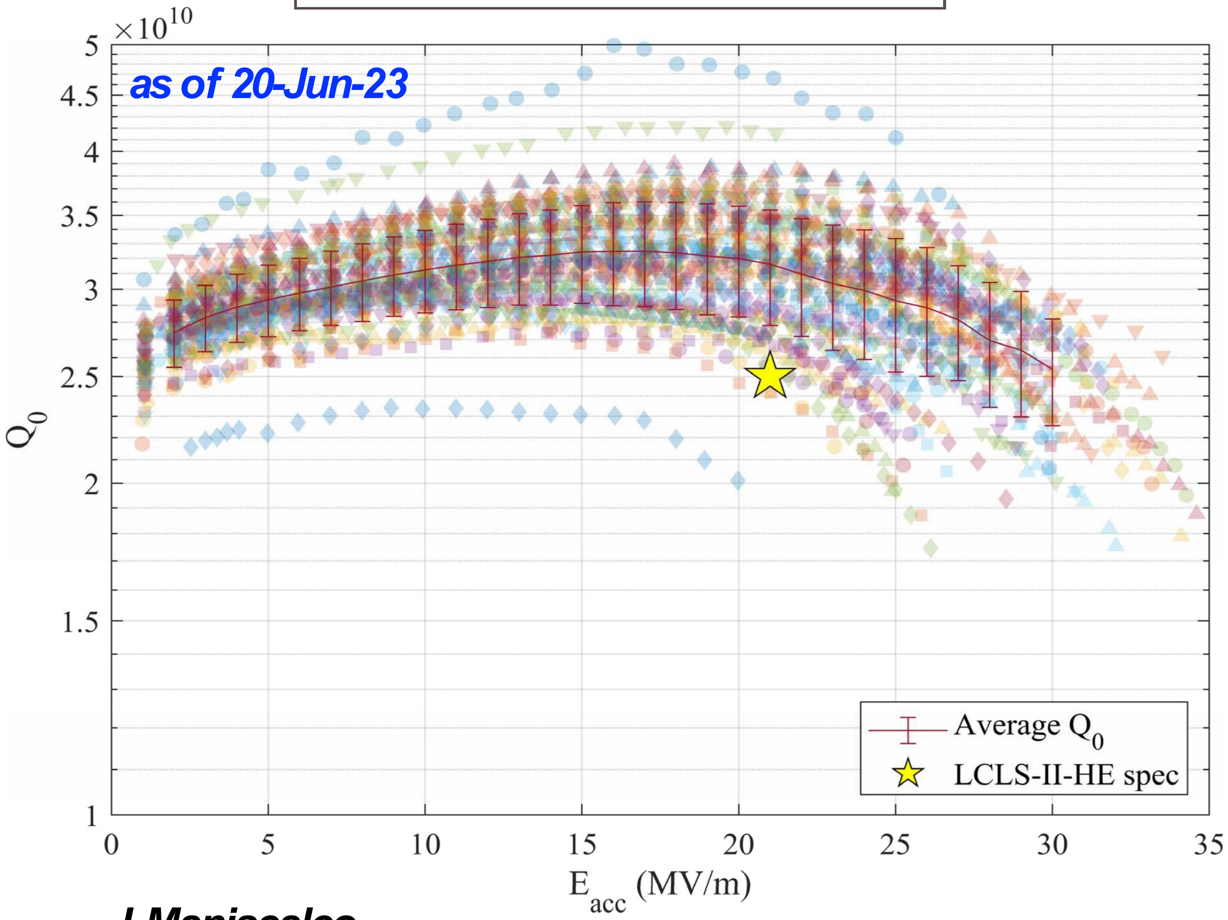
High-Q/High-gradient R&D outcome

- LCLS-II-HE incorporates the state-of-the art processing to achieve high-Q and high-gradient
- In average, cavities exceed both Q-factor and accelerating gradient

Industrialization of the process

- Technology transfer to industry was successful
  - Constant communication with vendor and in-person oversight by project SMEs
- Major issues
  - He vessel bellows damage and non-conformities
  - Higher yield loss than anticipated for eddy current scanning qualification of raw Nb material

All cavities with no FE



J. Maniscalco

M. Checchin @ SRF2023

Outlook on R&D for High Q_0 & High G

Reference for HighQ/HighG

Final EP cold: best surface finishing

High temperature annealing

from 800 °C to 900 °C

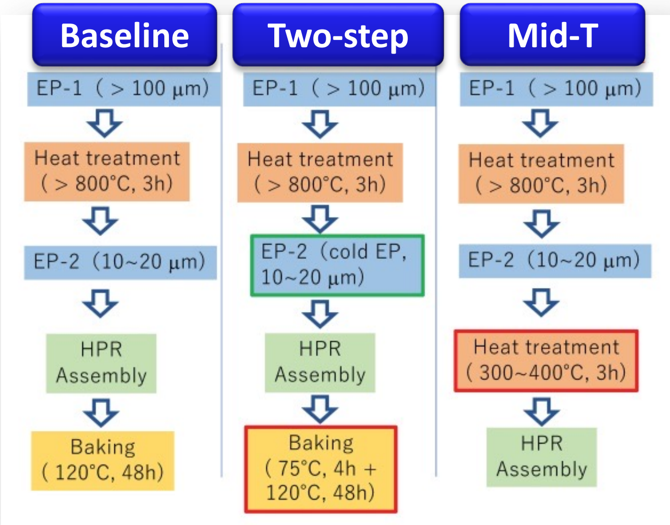
Final treatment for performances

120 °C: baseline

Two-step baking

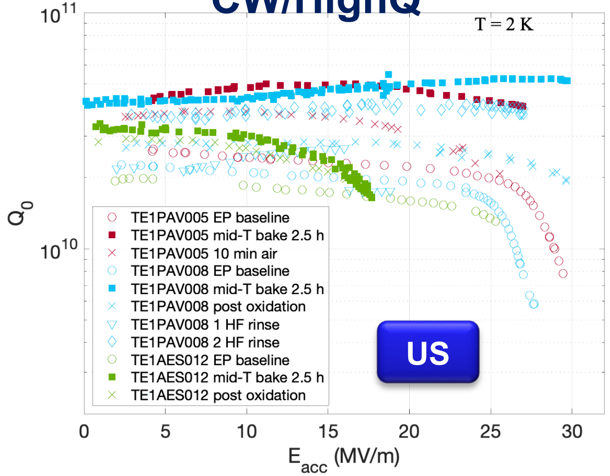
Mid-T baking

Nitrogen doping



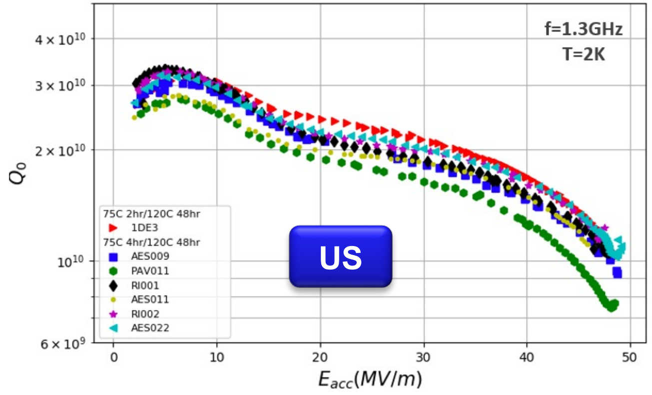
Mid-T baking

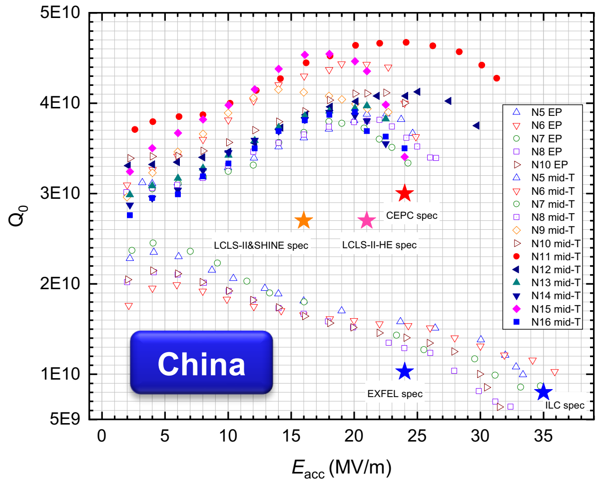
CW/HighQ

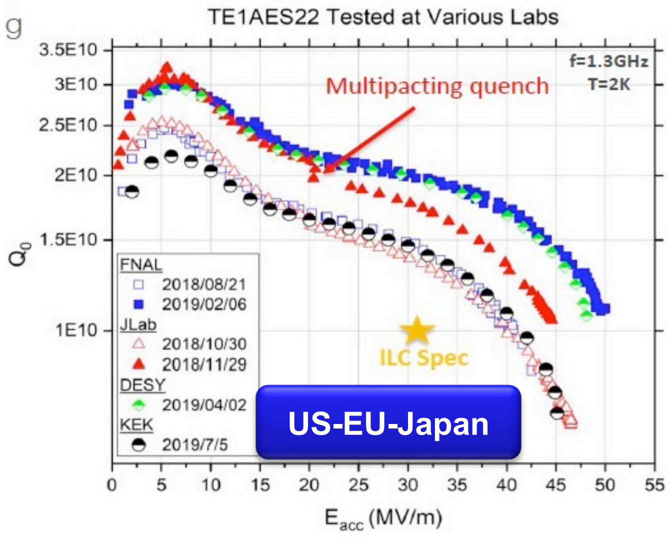


Two step baking

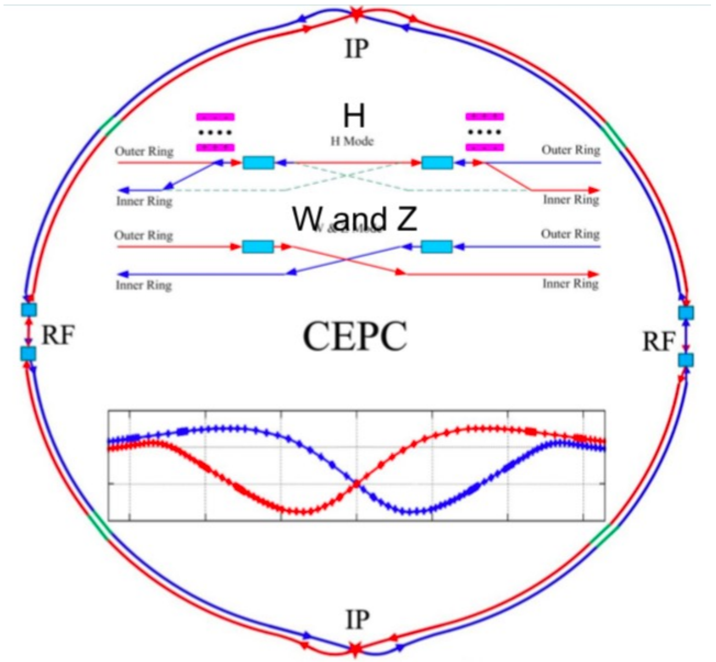
High G, ILC driven

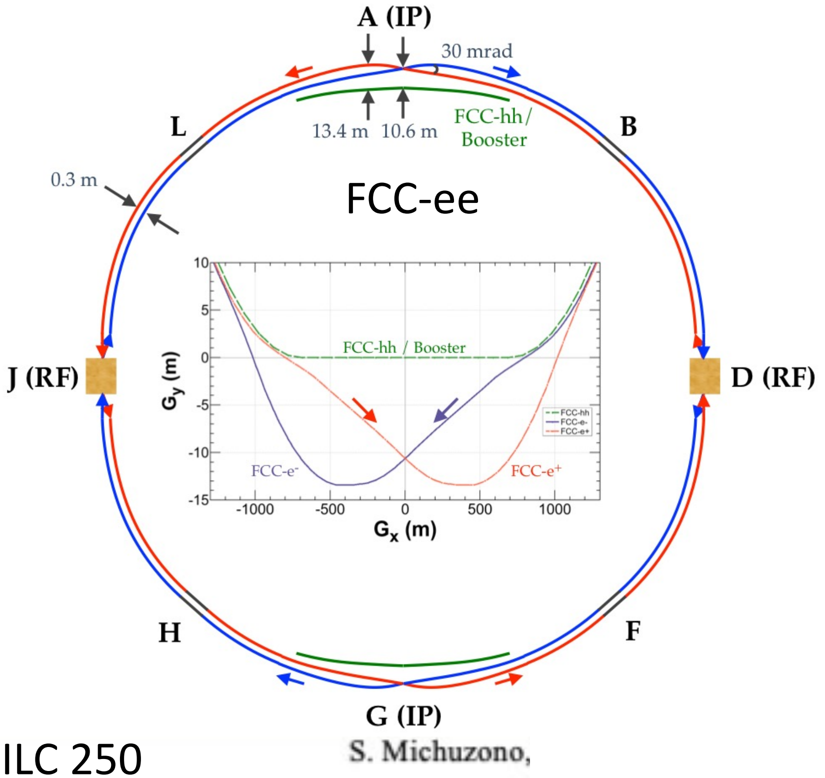


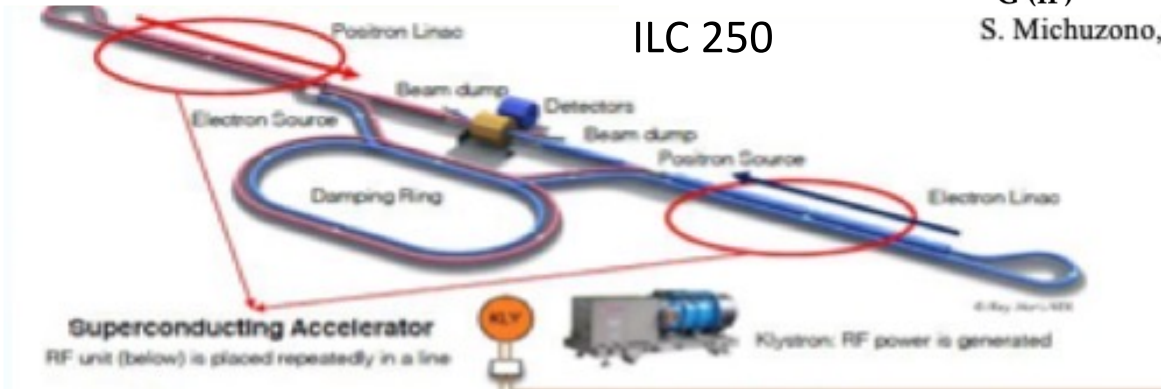


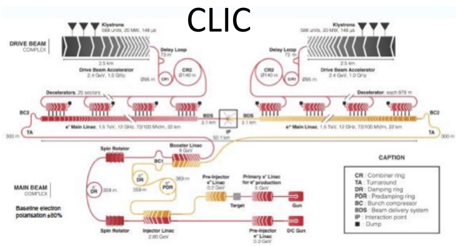


e⁺e⁻ Colliders: the three competitors need SRF









Thank you for your attention